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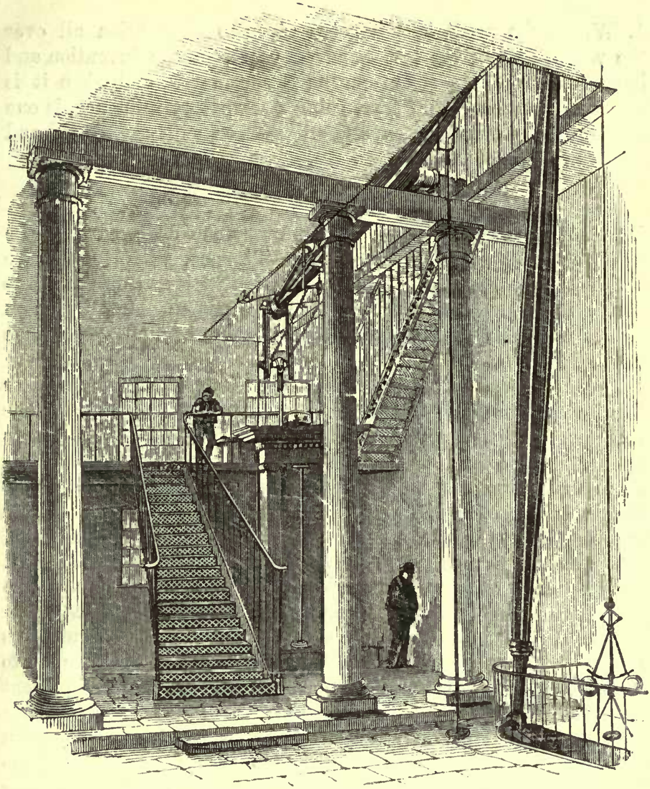

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THE STEAM ENGINE.

CHAPTER I.

1. The steam engine.—2. Consists of two essential parts.—3. The boiler. —4. Material employed in its formation.—5. Feeding apparatus.— 6. Importance of keeping the water in the boiler at a proper level.— 7. Wet and dry steam.—8. Priming.—9. Means of ascertaining the level of the water in the boiler.—10. Self-acting feeders.—11. Safety valve. —12. Steam gauge.—13. The furnace.—14. Proper mode of feeding the furnace.—15. Rarely observed.—16. Contrivance for supplying fuel.

1. When the prodigious impetus given to civilisation all over the world, during the last hundred years, by the invention and improvement of the steam-engine is considered, and when it is observed that this, so far from being a temporary influence, is one that has constantly gone on, and still goes on with augmented and vastly accelerated energy,

> Mobilitate viget viresque acquirit eundo,

it cannot be matter of surprise, that every one endowed with the most moderate gifts of sense and intelligence, whatever may be his position on the social scale, is animated with a strong desire to obtain some knowledge of the extraordinary machine by which results of such vast, enduring, and wide-spread importance have been attained.

Though comparatively few have the time, the inclination, or the peculiar intellectual aptitude to follow out the details of the mechanism of this great invention, as developed in its numerous applications to the various arts of life, all who are by circumstances and education raised above the condition of the rudest and most unskilled labourer have both the time and the mental qualifications to acquire a general acquaintance with the machine, and with the physical principles from which it derives its power. To this large class we now address ourselves, and propose to present them in a very brief compass with a general view of the principle and mechanism of the steam-engine, confining ourselves chiefly to those broad and general features which are common to all varieties of the machine, and discarding for the present such minute details of the mechanism as are applied only in particular forms of steam-engine, and which, though often admirable for ingenuity of design and contrivance, are nevertheless subordinate in interest when brought beside the larger and more general views we now refer to.

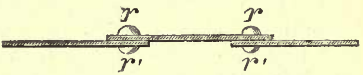
2. The steam-engine, whatever be its form or purpose, consists of two essentially different parts; the first, that in which the steam is generated, and the second, that in which the steam is worked. Although these taken together are essential to the performance of the machine, the name steam-engine in its strictest sense would signify only the latter, the former being called the boiler.

3. Boilers vary much in magnitude, form, structure, and even in material, according to the purpose to which they are applied, and the circumstances under which they are used. There are, however, certain characters common to all.

Every boiler consists of a reservoir for the water and steam, and a furnace with its appendages for the combustion of the fuel, the heat evolved from which is the physical agency by which the evaporation is produced and maintained. The boiler is formed of plates of metal, of suitable thickness, rivetted together, so as to be steam-tight, that is to say, so that steam cannot be forced between them.

The manner in which the plates are rivetted together is shown in fig. 1, the edges of the plates being laid one upon the other and their surfaces forced into steam-tight contact by rivets *r r′* passing through holes punched in them, the heads of the rivets being formed by the hammer while the iron is still soft by heat.

Fig. 1.



The appearance of the rows of rivets along the edges of the plates composing the boiler is shown in the general view of a waggon-boiler in fig. 7.

4. The material of the boiler is most commonly wrought iron. Copper is sometimes though very rarely used. It has an advantage over iron, inasmuch as it is a better conductor of heat, and is less liable to become incrusted by lime and other earthy matter, which is always held in solution by the water, and precipitated in the process of evaporation. It is also more durable than iron, but is excluded, save in rare and exceptional cases, because of its greater cost.

Cast iron, though cheaper than wrought iron, would be inadmissible for several reasons, one of which is its brittleness. If explosion happened it would fly in pieces, the fragments becoming destructive missiles. In case of explosion wrought iron would be ripped and torn. The one is tough, the other brittle.

5. The boiler is a reservoir not only for water but for steam. The steam, being much lighter, bulk for bulk, than water will always ascend in bubbles through the water, and will collect in the upper parts of the boiler. The space within the boiler, therefore, may be conceived to be divided at a certain level between the water and the steam. All the space below that level is appropriated to the water, all above it to the steam.

But according as the water is converted into steam, the quantity contained in the boiler being proportionally diminished, this level would fall continually lower and lower. That, however, is prevented by a FEEDING APPARATUS, which generally consists of forcing pumps, of adequate power, by which as much water is driven into the boiler as is converted into steam by the furnaces. This feeding apparatus is, in some cases, worked only from time to time to replenish the boiler, in other cases the supply is continual. In the former case, the level which separates the steam from the water alternately rises and falls within certain limits.

While the action of the feeding apparatus is suspended it falls gradually as the evaporation proceeds. When it has descended to a certain point the feeding apparatus is put in action and the level rises again to its former limit, after which it is again suspended, and so on. This rise and fall of the level of the water in the boiler is, or ought to be, restrained between such limits, that the level is never either injuriously high or injuriously low.

When the feeding apparatus works incessantly, the water in the boiler is kept always at the same level, the arrangements being such that by a self-adjusting mechanism, the quantity of water supplied to the boiler, from minute to minute, is exactly equal to the quantity evaporated.

6. The importance of keeping the boiler duly supplied with water will be easily understood. So long as those parts of the boiler which are exposed to the action of the furnace are filled with water the metal can never become unduly heated, because all the heat imparted by the furnace is absorbed by the water in evaporation. But if the level of the water were allowed to subside below any part which is exposed to the action of the furnace, the heat acting upon such parts not being taken up by the water, and the steam which in that case would alone be in contact with them, being a slow recipient of heat, the plates of the boiler would soon become red hot, and would consequently be softened, so as no longer to possess the strength necessary to resist the pressure within them, and the boiler would burst. For this reason, it is always of the utmost importance to provide means to ensure such a supply of water as shall prevent the level from ever falling below the highest parts upon which the furnace acts.

Inconvenience of a different kind would be produced by overfeeding, and consequently by raising the level of the water above a certain limit. When the water in a boiler is in a state of strong ebullition, which it always is in the boilers of engines in full operation, bubbles of steam are produced in great quantities in the lowest parts, these being the parts upon which the action of the furnace is most energetic. These bubbles, rising with violence to the surface, throw up the water in spray, so that the part of the boiler above the level of the water is filled with a mixture of pure steam and of particles of water in minute subdivision. The latter, however, fall back into the water by their gravity, provided that the space left for the steam have sufficient height. The upper part of that space will then be supplied with pure steam without intermixture with spray. But if the boiler be over-filled with water, so that the space left for the steam have so little height that more or less spray is mixed even with the highest parts of it, this spray will be drawn into the working part of the machine, and will be attended with the two-fold evil of injuring the performance of the engine and wasting a quantity of heat which would otherwise be employed in producing steam, and therefore producing mechanical power.

7. Nevertheless with all practicable precautions spray sometimes issues with the steam from the boiler to the engine. Steam, in this condition, is like the air when a fine misty rain floats in it, and is called WET STEAM by the engineers; the steam when free from this defect being called DRY STEAM. A handkerchief held in dry steam issuing from the valve of a boiler will be no more damped than it would be by a blast of wind; but if the steam be charged more or less with spray, its presence will be shown at once by the moisture it would deposit.

8. The spray with which wet steam is charged is called by the engineers PRIMING.

9. It appears, therefore, that whatever be the form of the machine, or the purpose to which it is applied, it is of great importance so to regulate the feed of the boiler, that the level of the water in it shall neither fall too low nor rise too high.

Considering then the great importance of keeping the level of the water in the boiler within the limits here defined, it will be evident that some expedient ought to be provided by means of which the engineman can at all times ascertain what the level of the water actually is.

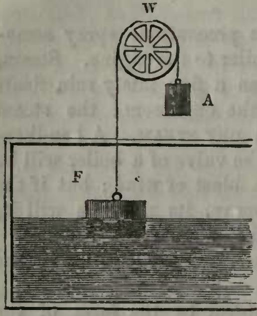
Different methods, all more or less efficient and ingenious, have been invented for accomplishing this object.

One of the most simple consists in two common cocks, called gauge cocks, like those used in a beer barrel, which are inserted in the side or end of the boiler, one of which is placed at the lowest, and the other at the highest limit of the water level. If the engineman, on opening the latter, finds that water issues from it, he knows that the level has risen to its highest limit, and he suspends the feed. If, on opening the former, he finds the steam issue from it, he knows that the water level has fallen too low, and he lays on the feed. But so long as water issues from the one and steam from the other, he knows that the water level is within the required limits.

This method, though generally adopted, is not exclusively depended on, and others are used.

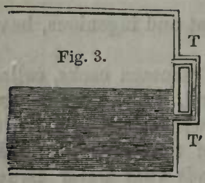
A weight F (fig. 2), half immersed in the water, is supported by a wire, which, passing steam-tight through a small hole in the top, is connected by a flexible string or chain, passing over a wheel W, with a counterpoise A, just sufficient to balance F when half immersed. If F be raised above the water, A being lighter will no longer balance it, and F will descend pulling up A, and turning the wheel W. If F be plunged deeper in the water, A will more than balance it, and will pull it up, so that the only position in which F and A will balance each other is, when F is half immersed. The wheel W is so adjusted, that when two pins placed on its rim are in the horizontal position, the water is at its proper level. Consequently it follows, that if the water rise above this level, the weight F is lifted and A falls, so that the pins come into another position, and if it fall lower, F falls and A rises, so that the pins assume a different position. Thus, in general, the position of the pins becomes an indication of the quantity of water in the boiler.

Fig. 2.



Another method is to place a glass tube (fig. 3), with one end T entering the boiler above the proper level, and the other end T′ entering it below the proper level. It must be evident that the water in the tube will always stand at the same level as the water in the boiler, since the lower part has a free communication with that water, while the surface is submitted to the pressure of the same steam as the water in the boiler. This and the last-mentioned gauge have the advantage of addressing the eye of the engineer at once, without any adjustment; whereas the gauge-cocks must be both opened, whenever the depth is to be ascertained.

Fig. 3.

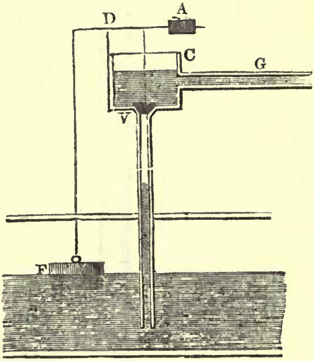


These gauges, however, require the constant attention of the engine-man; and it becomes desirable either to find some more effectual means of awakening that attention, or to render the supply of the boiler independent of any attention. In order to enforce the attention of the engineman to replenish the boiler when partially exhausted by evaporation, a tube was sometimes inserted at the lowest level to which it was intended that the water should be permitted to fall. This tube was conducted from the boiler into the engine-house, where it terminated in a mouthpiece or whistle, so that whenever the water fell below the level at which this tube was inserted in the boiler, the steam would rush through it, and issuing with great velocity at the mouthpiece, would summon the engineer to his duty with a call that would rouse him even from sleep.

In the most effectual of these methods, the task of replenishing the boiler must still be executed by the engineer; and the utmost that the boiler itself was made to do, was to give due notice of the necessity for the supply of water. The consequence was, among other inconveniences, that the level of the water was subject to constant variation.

10. To remedy this a method has been invented, by which the engine is made to feed its own boiler. The pipe G (fig. 4), which leads from the hot water pump, terminates in a small cistern C in which the water is received. In the bottom of this cistern, a valve V is placed, which opens upwards and communicates with a feed pipe, which descends into the boiler below the level of the water in it. The stem of the valve V is connected with a lever turning on the centre D, and loaded with a weight F dipped in the water in the boiler in a manner similar to that described in fig. 2, and balanced by a counterpoise A in exactly the same way. When the level of the water in the boiler falls, the float F falls with it, and pulling down the arm of the lever raises the valve V, and lets the water descend into the boiler from the cistern C. When the boiler has thus been replenished, and the level raised to its former place, F will again be raised, and the valve V closed by the weight A. In practice, however, the valve V adjusts itself by means of the effect of the water on the weight F, so as to permit the water from the feeding cistern C to flow in a continued stream, just sufficient in quantity to supply the consumption from evaporation, and to maintain the level of the water in the boiler constantly the same.

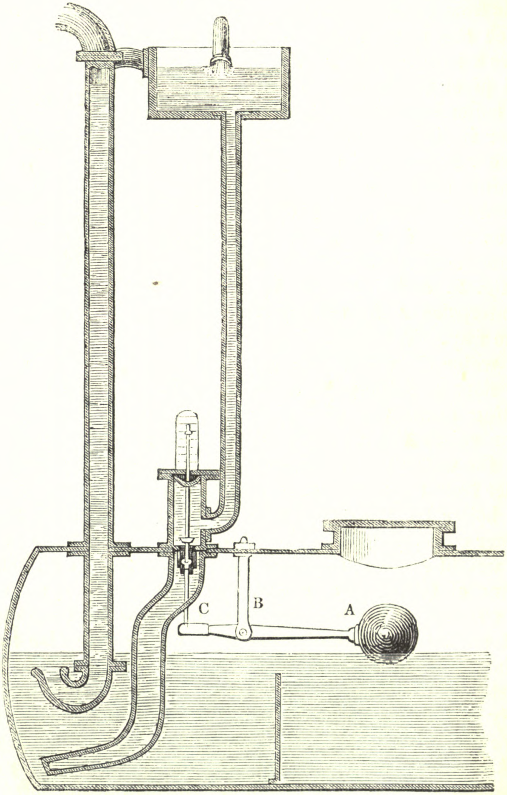
Fig. 4.



By this arrangement the boiler is made to replenish itself; or, more properly speaking, it is made to receive such a supply, as that it never wants replenishing—an effect which no effort of attention on the part of an engineman could produce. But this is not the only good effect produced by this contrivance. A part of the steam which originally left the boiler, having discharged its duty in moving the engine, is lodged in the hot well C (fig. 4), and is again restored to the source from which it came, bringing back to the boiler all the unconsumed portion of its heat preparatory to being once more put in circulation through the machine.

Another method of arranging a self-regulating feeder is shown in fig. 5. A is a hollow ball of metal attached to the end of a lever, whese fulcrum is at B. The other arm of the lever C is connected with the stem of a spindle valve, communicating with a tube which receives water from the feeding cistern. Thus, when the level of the water in the boiler subsides, the ball A preponderating over the weight of the opposite arm, the lever falls, the arm C rises and opens the valve, and admits the feeding water.

Fig. 5.



This apparatus will evidently act in the same manner and on the same principles as that already described.

11. In different applications of the engine, steam of different pressure is required. The pressure of steam is usually expressed by stating the number of pounds weight upon each square inch of surface which would exactly resist or balance it. All boilers are provided with a valve which opens outwards, and which is loaded with a certain limited and regulated weight. When the bursting pressure with which the steam urges this valve exceeds the weight with which it is loaded, the valve yields, is opened, and the steam escapes through it, and thus continues to escape until the quantity pent up in the boiler is so diminished, that its pressure upon the valve no longer exceeds the weight with which the valve is loaded. When this happens, the valve will remain closed, but will be ready to yield and to open upon the least increase of the pressure of the steam.

Such a valve is called a "safety valve" for the obvious reason that it prevents the pressure of the steam in the boiler from ever attaining such a force as would endanger the boiler.

It sometimes happens that it is necessary to vary from time to time the pressure of the steam according to the work to which the engine is applied, and consequently to vary the weight upon the safety valve. In such cases it is usual to provide two safety valves, one of which shall be regulated by the engineer, and the other placed out of his power. The latter in that case is loaded with the greatest pressure which the boiler can bear without danger; so that even though the engineer should indiscreetly load the valve left at his disposition beyond the limit of safety, the other valve would yield the moment the steam attained a dangerous pressure.

Safety valves are of numerous forms. They consist usually of a circular aperture cut in the boiler, with conical edges inclining from within outwards. In this is placed a circular plate or stopper of corresponding size, with corresponding conical edges, so that it shall exactly fit the aperture; and when pressed upon it, the conical edges shall be in steam-tight contact. This circular plate is attached at its centre to an iron rod, which rises perpendicular to it. Upon this rod sliding weights are placed so as to press down the valve with a greater or less force, according as their number is increased or diminished.

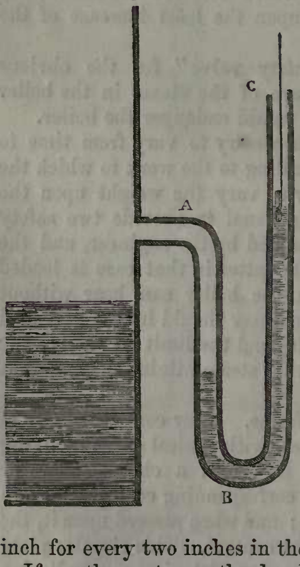
In the general view of a boiler of the form called waggon boiler, shown in fig. 7, the safety valve is shown at N. It is provided with a handle, by means of which the engineman can raise it when necessary.

12. It is necessary to provide a ready method of indicating at all

times the actual pressure of the steam in the boiler. Various methods are used for this purpose. In boilers where steam of great pressure is used, the pressure is indicated by a spring gauge, similar in its principle to those used for steel yards to weigh bodies in commerce. The pressure of the steam acts against a valve which is connected with the arm of the lever of the steel-yard, the other arm being connected with the spring. In this way the varying tension of the spring is made to measure the pressure on the valve.

When steam of low pressure is used, an expedient called a mercurial steam gauge is used. A bent tube containing mercury is inserted into some part of the apparatus, which has free communication with the steam. Let A B C (fig. 6), be such a tube. The pressure of the steam forces the mercury down in the leg A B, and up in the leg B C. If the mercury in both legs be at exactly the same level, the pressure of the steam must be exactly equal to that of the atmosphere; because the steam pressure on the mercury in A B balances the atmospheric pressure on the mercury in B C. If, however, the level of the mercury in B C be above the level of the mercury in B A, the pressure of the steam will exceed that of the atmosphere. The excess of its pressure above that of the atmosphere may be found by observing the difference of the level of the mercury in the tubes B C and B A, allowing a pressure of one pound on each square inch for every two inches in the difference of the levels.

Fig. 6.



If, on the contrary, the level of the mercury in B C should fall below its level in A B, the atmospheric pressure will exceed that of the steam, and the quantity of the excess may be ascertained exactly in the same way.

If the tube be glass, the difference of levels of the mercury would be visible; but it is most commonly made of iron; and, in order to ascertain the level, a thin wooden rod with a float is inserted in the open end of B C, so that the portion of the stick within the tube indicates the depth of the level of the mercury below its mouth.

13. The most important appendage of the boiler is the furnace, which consists of a grate, upon which the fuel is maintained in combustion,—a system of flues, by which the flame and heated gases proceeding from the fuel in combustion are conducted in contact with the boiler, so as to impart more or less of their heat to the boiler, and, in fine, a chimney by which these gases escape into the atmosphere, and which maintains the draft necessary to give effect to the combustion.

The explanation of the furnace and its appendages, as well as that of the boiler already given, will be rendered much more easily intelligible by the aid of the figures 7, 8, 9, and 10, which, though they represent a particular form of boiler, indicate those provisions and arrangements which are most generally used in boilers of all forms.

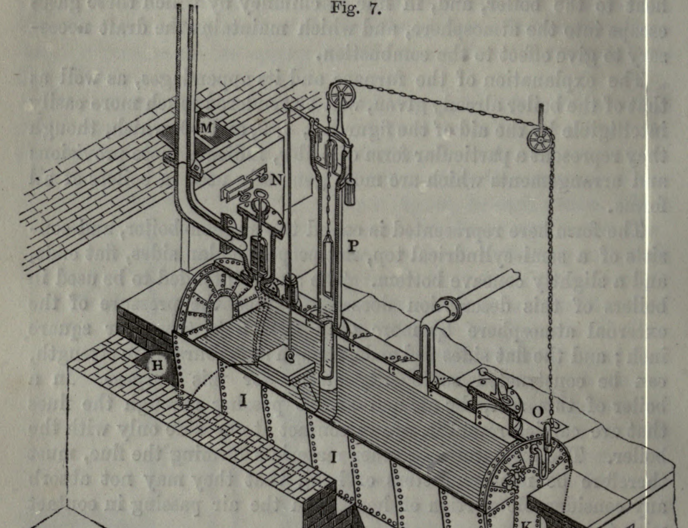
The form here represented is called the waggon-boiler, and consists of a semi-cylindrical top, flat perpendicular sides, flat ends, and a slightly concave bottom. The steam intended to be used in boilers of this description does not exceed the pressure of the external atmosphere by more than from 3 to 5lbs. per square inch; and the flat sides and ends, though unfavourable to strength, can be constructed sufficiently strong for this purpose. In a boiler of this sort, the air and smoke passing through the flues that are carried round it, are in contact at one side only with the boiler. The brickwork, or other materials forming the flue, must therefore be non-conductors of heat, that they may not absorb any considerable portion of heat from the air passing in contact with them.

A perspective view of the boiler and furnace is presented in fig. 7. The grate and a part of the flues are rendered visible by the removal of a portion of the surrounding masonry in which the boiler is set. The interior of the boiler is also shown by cutting off one half of the semi-cylindrical roof. A longitudinal vertical section is shown in fig. 8, and a cross section in fig. 9. A horizontal section taken above the level of the grate, and below the level of the water in the boiler, shewing the course of the flues, is given in fig. 10. The corresponding parts in all the figures are marked by the same letters.

14. The door by which fuel is introduced upon the grate is represented at A, and the door leading to the ash-pit at B. The fire bars at C slope downwards from the front at an angle of about 25°, giving a tendency to the fuel to move from the front towards the back of the grate. The ash-pit D is constructed of such a magnitude, form, and depth, as to admit a current of atmospheric air to the grate-bars, sufficient to sustain the combustion. The form of the ash-pit is usually wide below, contracting towards the top.

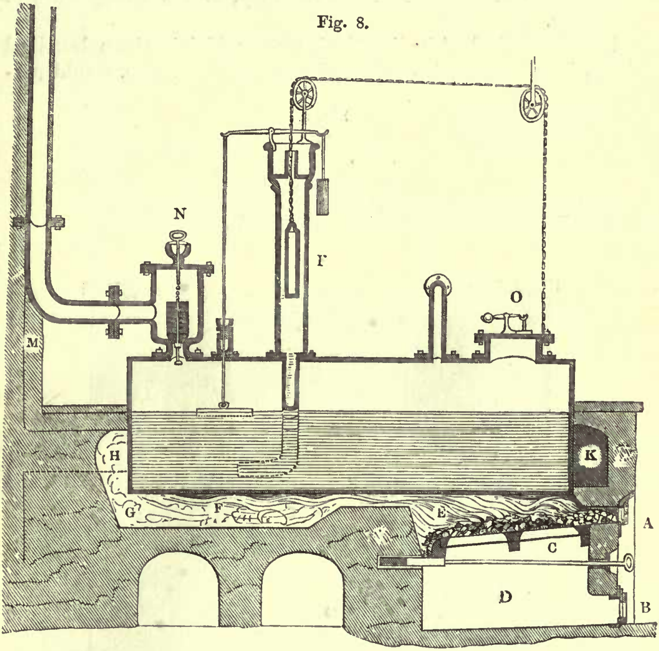
The fuel, when introduced at the fire-door A, should be laid on that part of the grate nearest to the fire-door, called the dead plates: there it is submitted to the process of coking, by which the gases and volatile matter which it contains are expelled, and being carried by a current of air admitted through small apertures in the fire-door over the burning fuel in the hinder part of the grate, they are burnt. When the fuel in front of the grate has been thus *coked*, it is pushed back, and a fresh feed introduced in front. The coal thus pushed back soon becomes vividly ignited, and by continuing this process, the fuel spread over the grate is maintained in the most active state of combustion at the hinder part of the grate. By such an arrangement, the smoke produced by the combustion of the fuel may be burnt before it enters the

Fig. 7.



flues. The flame and heated air proceeding from the burning fuel arising from the grate, and rushing towards the back of the furnace, passes over the *fire-bridge* E, and is carried through the flue F which passes under the boiler. This flue (the cross section of which is shown in fig. 9, by the dark shade put under the boiler), is very nearly equal in width to the bottom of the boiler, the space at the bottom of the boiler, near the corners, being only what is sufficient to give the weight of the boiler support on the

Fig. 8.



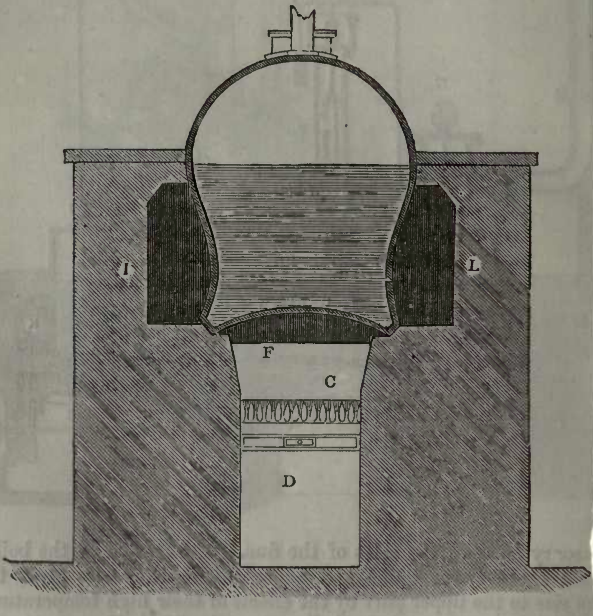
masonry forming the sides of the flue. The bottom of the boiler being concave, the flame and heated air as they pass along the flue rise to the upper part by the effects of their high temperature, and *lick* the bottom of the boiler from the fire-bridge at E to the further end G.

At G the flue rises to H, and turning to the side of the boiler at I I, conducts the flame in contact with the side from the back to the front; it then passes through the flue K across the front, and returns to the back by the other side flue L. The side flue is represented, stripped of the masonry, in fig. 7, and also appears in the plan in fig. 10, and in the cross section in fig. 9. The course of the air is represented in fig. 10 by the arrows. From the flue L the air is conducted into the chimney at M.

By such an arrangement, the flame and heated air proceeding from the grate are made to circulate round the boiler, and the length and magnitude of the flues through which they are conducted should be such, that when they arrive at the chimney their temperature shall be reduced, as nearly as is consistent with the maintenance of draught in the chimney, to the temperature of the water.

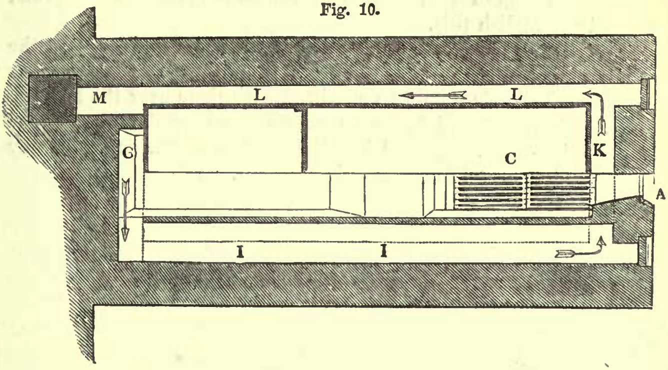
15. The method of feeding the furnace, which has been described above, is one which, if conducted with skill and care, would produce a much more perfect combustion of the fuel than would attend the common method of filling the grate from the back to the front with fresh fuel, whenever the furnace is fed. This method, however, is rarely observed in the management of the furnace. It requires the constant attention of the stokers (such is the name given to those who feed the furnaces). The fuel must

Fig. 9.



be supplied, not in large quantities, and at distant intervals, but in small quantities and more frequently. On the other hand, the more common practice is to allow the fuel on the grate to be in a great degree burned away, and then to heap on a large quantity of fresh fuel, covering over with it the burning fuel from the back to the front of the grate. When this is done, the heat of the ignited coal acting upon the fresh fuel introduced, expels the gases combined with it, and, mixed with these, a quantity of carbon, in a state of minute division, forming an opaque black smoke. This is carried through the flues and drawn up the chimney. The consequence is, that not only a quantity of solid fuel is sent out of the chimney unconsumed, but the hydrogen and other gases also escape unburned, and a proportional waste of the combustible is produced; besides which, the nuisance of an atmosphere filled with smoke ensues. Such effects are visible to all who observe the chimneys of steam vessels, while the engine is in operation. When the furnaces are thus filled with fresh fuel, a large volume of dense black smoke is observed to issue from the chimney. This gradually subsides as the fuel on the grate is ignited, and does not reappear until a fresh feed is introduced.

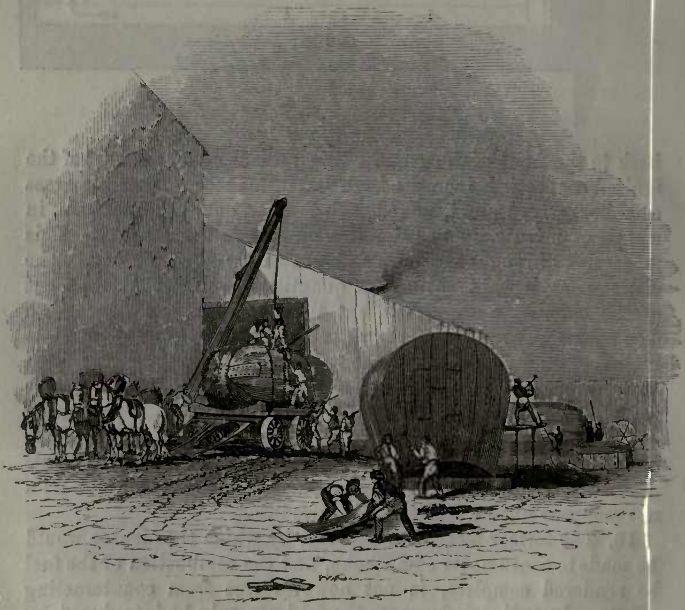
Fig. 10.



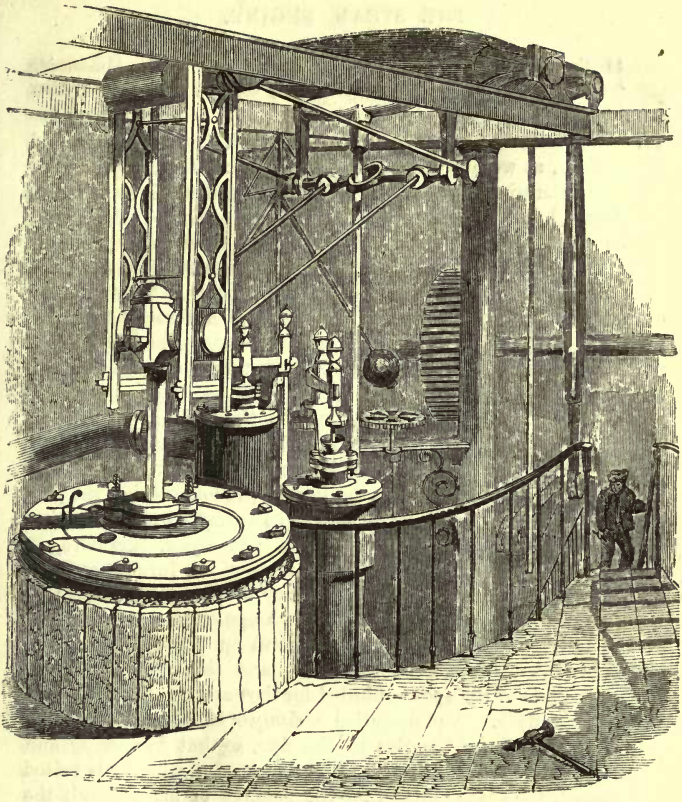
16. The former method of feeding, by which the furnace would be made to consume its own smoke, and the combustion of the fuel be rendered complete, is not however free from counteracting effects. In ordinary furnaces the feed can only be introduced by opening the fire-doors, and during the time the fire-doors are opened a volume of cold air rushes in, which passing through the furnace is carried through the flues to the chimney. Such is the effect of this in lowering the temperature of the flues, that in many cases the loss of heat occasioned is greater than any economy

of fuel obtained by the complete consumption of smoke. Various methods, however, may be adopted by which fuel may be supplied to the grate without opening the fire-doors, and without disturbing the supply of air to the fire. A hopper built into the front of the furnace, with a moveable bottom or valve, by which coals may be allowed to drop in from time to time upon the front of the grate, would accomplish this.

In order to secure the combustion of the gases evolved from the coals placed in the front of the grate, it is necessary that a supply of atmospheric air should be admitted with them over the burning fuel. This is effected by small apertures or regulators, provided in the fire-doors, governed by sliding plates, by which they may be opened or closed to any required extent.



BOILER MANUFACTORY.



DOUBLE-ACTING ENGINE—CITY SAW-MILLS.

THE STEAM ENGINE.

◆

CHAPTER II.

17. Method of regulating the activity of the furnace.—18. How steam is made to produce a mechanical effect.—19. The cylinder and piston.—20. Metallic pistons.—21. Estimate of the force with which the piston is moved.—22. Transmission of this force.—23. Piston rod.—24. Cocks, valves, and slides.—25. How employed.—26. Stroke of the engine.—27. Effective pressure.—28. Supply of steam to the cylinder.—29. By valves.—30. By slides.—31. Seaward's slides.—32. Single cock.—33. Four-way cock.—34. Low and high pressure, more properly called condensing and non-condensing, engines.—35. Objections

to the latter and countervailing advantages. — 36. Condensing engines.—37. Condensing apparatus.—38. Air-pump.—39. Cold water pump.—40. Hot water pump.

17. WHATEVER be the form of boiler used, its magnitude and proportions, as well as those of the furnaces and their appendages, must be determined by the rate at which the steam is required to be produced, and in some degree also by the quality of the fuel.

The principle upon which a chimney more or less lofty produces a draft through the fuel in a fire-place in connection with it, has been already explained in our Tract on "Fire." The chimney connected with the furnace of a steam-boiler acts on the same principle, and its dimensions and height must necessarily be proportionate to those of the furnace, and to the quantity of fuel to be consumed in a given time.

But since the evaporation produced in the boiler requires to be varied with the varying work exacted from the engine; and since this evaporation will necessarily be proportionate to the rate at which the fuel is consumed in the furnace, it follows that the rate of combustion in the furnace should be varied with the varying power to be exacted from the engine. In order, therefore, to maintain this proportion between the force of the furnace and the demands upon the engine, it is necessary to stimulate or mitigate the furnace, as the evaporation is to be augmented or diminished.

The activity of the furnace must depend on the current of air which is drawn through the grate bars, and this will depend on the magnitude of the space afforded for the passage of that current through the flues. A plate called a *damper* is accordingly placed with its plane at right angles to the flue, so that by raising and lowering it in the same manner as the sash of a window is raised or lowered, the space allowed for the passage of air through the flue may be regulated. This plate might be regulated by the hand, so that by raising or lowering it the draught might be increased or diminished, and a corresponding effect produced on the evaporation in the boiler: but the force of the fire is rendered uniformly proportional to the rate of evaporation by the following arrangement, without the intervention of the engineer. The column of water sustained in the feed pipe (figs. 7, 8), represents by its weight the difference between the pressure of steam within the boiler and that of the atmosphere. If the engine consumes steam faster than the boiler produces it, the steam contained in the boiler acquires a diminished pressure, and consequently the column of water in the feed pipe will fall. If, on the other hand, the boiler produce steam faster than the engine consumes it, the accumulation of steam in the boiler will cause an increased pressure on the water it contains, and thereby increase the height of the column of water sustained in the feed pipe. This column, therefore, necessarily rises and falls with every variation in the rate of evaporation in the boiler. A hollow float P is placed upon the surface of the water of this column; a chain connected with this float is carried upwards, and passed over two pulleys, after which it is carried downwards through an aperture leading to the flue which passes beside the boiler: to this chain is attached the damper. By such an arrangement it is evident that the damper will rise when the float P falls, and will fall when the float P rises, since the weight of the damper is so adjusted, that it will only balance the float P when the latter rests on the surface of the water.

Whenever the evaporation of the boiler is insufficient, it is evident from what has been stated, that the float P will fall and the damper will rise, and will afford a greater passage for air through the flue. This will stimulate the furnace, will augment its heating power, and will therefore increase the rate of evaporation in the boiler. If, on the other hand, the production of steam in the boiler be more than is requisite for the supply of the engine, the float will be raised and the damper let down, so as to contract the flue, to diminish the draught, to mitigate the fire, and therefore to check the evaporation. In this way the excess, or defect, of evaporation in the boiler is made to act upon the fire, so as to render the heat proceeding from the combustion as nearly as possible proportional to the wants of the engine.

18. Having thus explained generally the principal expedients by which the efficiency of the boiler and furnace of a steam-engine is maintained, it will be only necessary to add, that although these expedients, in the forms in which they are represented in the diagrams, will not be found in every steam boiler, yet equivalents to them in other forms or positions are almost universal. In certain cases the self-regulating apparatus of the boiler and furnace are excluded by want of the necessary height, and then the proper regulation of the machine must depend on the skill and vigilance of those who are in charge of it.

Supposing, then, that by these or other similar or equivalent provisions a supply of steam in the necessary quantity and of the requisite pressure is obtained, it remains to show how the steam is made to produce the desired mechanical effect.

The method universally adopted to render the power of steam available for mechanical purposes is that of a solid piston moving freely in a hollow cylinder in steam-tight contact with its sides. The steam is admitted alternately at one end and at the other, of the cylinder. When it is let in at either end, it is permitted to escape by the other, so that the piston is blown by the steam alternately from end to end of the cylinder. The ends of the cylinder are closed by steam-tight covers, but proper openings are provided for the alternate admission and escape of the steam.

19. The cylinder is made of cast iron of adequate thickness and strength. It is bored with the nicest precision, so that its inner surface is truly cylindrical and of uniform diameter from end to end. The piston is also made of iron, and its contact with the cylinder is rendered steam-tight, either by a packing of hemp and soft rope, called gasket, which fills a circular groove or channel surrounding the piston, or by constructing the external rim of the piston of several metallic segments, which are urged against the side of the cylinder by springs which act upon them from the centre of the piston.

A section of a packed piston is given in fig. 11. The hollow groove containing the packing is represented at the sides next the cylinder, and the top is attached to the piston by screws, by turning which the packing is compressed so as to be forced outwards against the sides of the cylinder until it is in steam-tight contact with them.

Fig. 11.

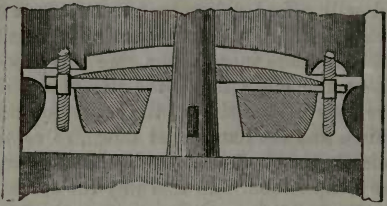
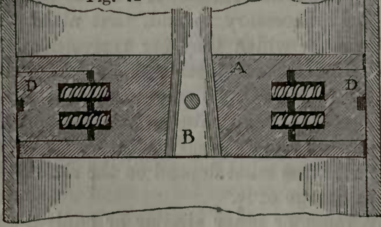


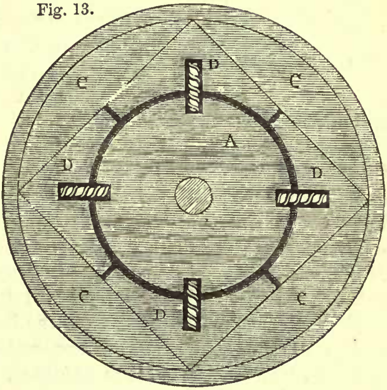
Fig. 12.



20. Pistons which maintain steam-tight contact with the cylinder without packing, and which are called metallic pistons, are of very various construction, though all of essentially the same principle. One of these is represented in section in fig. 12, and in plan in fig. 13, p. 21. A deep groove, square in its section, is formed around the piston, so that while the top and bottom form circles equal in magnitude to that of the cylinder, the intermediate part of the body forms a circle less than the former by the depth of the groove. Let a ring of brass, cast iron, or cast steel, be made to correspond in magnitude and form with this groove, and let it be divided, as represented in fig. 13, into four segments C C C C, and four corresponding angular pieces, D D D D. Let the groove which surrounds the piston be filled by the four segments with the four wedge-like angular pieces within them, and let the latter be urged against the former by eight spiral springs, as represented

in fig. 12 and fig. 13. These springs will abut against the solid centre of the piston, and will urge the segments C against the cylinder. The spiral springs which urge the wedges are confined in their action by steel pins which pass through their centre, and by being confined in cylindrical cavities worked into the wedges and into corresponding parts of the solid centre of the piston, as the segments C wear, the springs urge the wedges outwards, and the points of the latter protruding, are gradually worn down so as to fill up the spaces left between the segments, and thus to complete the outer surface of the piston.

Fig. 13.



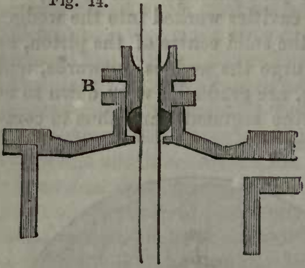
21. The force with which the piston is moved from end to end of the cylinder is estimated by the pressure of the steam which acts upon it, diminished by the reaction of the steam escaping from the side towards which it moves, and the resistance produced by its friction against the sides of the cylinder.

22. The mechanical force with which the piston is thus moved would be practically useless unless an expedient were provided by which it could be transmitted to some convenient point outside the cylinder, and since it is essential that the steam which impels the piston shall be confined within the cylinder, and that no air be allowed to enter, so as to react on the other side of the piston by its pressure, it is also essential that whatever be the means of transmitting the force of the piston to the outside of the cylinder, it shall be accomplished without leaving any interstitial space through which steam can escape or air enter.

23. This object is perfectly attained by a very simple contrivance. A hole is made through the centre of the piston, in which a truly formed cylindrical iron rod, called the piston-rod, is inserted and firmly fixed by a key or linch-pin. This piston-rod passes through a hole made in the iron cover of the cylinder, as shown in fig. 14. The piston-rod is kept in steam-tight contact with the edges of the hole by a contrivance called a *stuffing box*, B, represented in fig. 14. The hole made in the cover of the cylinder is very little greater in magnitude than

the diameter of the piston rod. Above this hole is a cup, in which, around the piston, is placed a stuffing of hemp or tow, which is saturated with oil or melted tallow. This collar of hemp is pressed down by another piece, also perforated with a hole through which the piston rod plays, and which is screwed down on the said collar of hemp.

Fig. 14.



The piston-rod, by this contrivance, being moved with the same alternate motion, and the same force as the piston itself, can be made to impart that force to any suitable piece of mechanism outside the cylinder, with which it may be put in connection.

24. Since the ends of the cylinder are closed by metallic covers, in the manner explained above, the openings for the exit and entrance of the steam at the ends, are placed, not in the covers, but in the sides, at points in immediate contiguity with the covers. These openings are governed by contrivances of various forms, and variously denominated COCKS, VALVES, and SLIDES.

25. Let two openings be imagined to be provided at each end of the cylinder, one leading from the boiler, and the other for the escape of the steam. Let stop-cocks, or valves, or sliding shutters, be adapted to these openings, so that they can be closed or opened by acting upon the handles of the cock valve or slide, and let these handles be supposed to be put in such connection with the piston-rod that when the piston arrives at either end of the cylinder the handles are driven by the rod, so as to open the passage which admits steam to the end of the cylinder at which the piston has arrived, and to close the passage which is provided for its escape, and, on the contrary, to open the passage for the escape of the steam from the other end of the cylinder, and to close the passage for its admission from the boiler. By this means the piston, being acted upon by the steam at the end at which it has arrived, and, being relieved from the action of the steam on the other side of it, will be driven to the other end of the cylinder where the piston-rod will again act upon the handles of the cocks, valves, or slides, so as to reverse the flow of the steam, allowing that which has just impelled the piston to escape, and introducing steam from the boiler to the end of the cylinder at which the piston has just arrived. In this way the piston will be driven back to the other end of the cylinder, and so on alternately from end to end.

26. We are accustomed to consider the cylinder in a vertical position, to call the covers of its ends the top and bottom, and to speak of the up stroke and the down stroke of the piston. Such is very often the position of the apparatus, but it is not necessarily nor always so. The cylinder is often horizontal. It is almost always so, for example, in locomotive engines, and often so in steamboat engines. It is sometimes placed in an inclined position, and is sometimes moveable, changing its position with the motion of the piston.

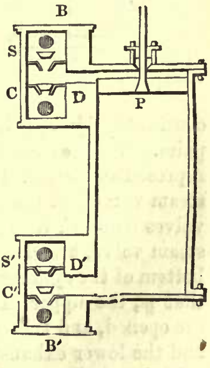
The motion of the piston from end to end of the cylinder is called its STROKE, and the dimensions are usually expressed by stating the diameter of the piston and the length of the stroke.

27. The EFFECTIVE PRESSURE of steam per square inch on the piston is found by deducting from the actual pressure the reaction of the steam escaping, and the friction. This effective pressure being multiplied by the number of square inches in the piston, which is known by its diameter, gives the total effective force of the piston, and this force, multiplied by the number of feet through which the piston moves per minute, which is known by the length of the stroke, and observing the number of strokes per minute, will give the actual mechanical force produced per minute by the steam acting on the piston.

28. From what has been explained it will be apparent that much of the efficiency of the machine must depend upon the precision and regularity with which the steam is alternately admitted to and withdrawn from either end of the cylinder. If it be admitted or withdrawn too soon or too late, it will either obstruct the force of the piston, or delay its return to the other end of the cylinder. For these reasons, and also because there is much beauty and ingenuity in the contrivances by which the steam is admitted and withdrawn, we shall here explain a few of the expedients by which that object is attained.

29. In the arrangement represented in fig. 15, the object is attained by four conical valves, two placed at each end of the cylinder. Let B and B′ be two steam boxes, B the upper, and B′ the lower, communicating respectively with the top and bottom of the cylinder by proper passages D D′. Let two valves be placed in B, one, S, above the passage D, and the other, C, below it; and in like manner two other valves in the lower valve box B′, one, S′, above the passage D, and the other C′, below it. Above the valve S in the upper steam box is an opening at which the steam

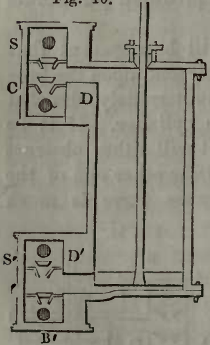
Fig. 15.



pipe from the boiler enters, and below the valve c is another opening, at which enters the exhausting pipe. In like manner, above the valve s′ in the lower steam box enters a steam pipe leading from the boiler, and below the valve c′ enters an exhausting pipe. It is evident, therefore, that steam can always be admitted above the piston by opening the valve s, and below it by opening the valve s′; and, in like manner, steam can be withdrawn from the cylinder above the piston, by opening the valve c, and from below it by opening the valve c′.

Supposing the piston P to be at the top of the cylinder, and the cylinder below the piston to be filled with pure steam, let the valves s and c′ be opened, the valves c and s′ being closed, as represented in fig. 15. Steam from the boiler will, therefore, flow in through the open valve s, and will press the piston downwards, while the steam that has filled the cylinder below the piston will pass through the open valve c′ into the exhausting pipe. The piston will, therefore, be pressed downwards by the action of the steam above it. Having arrived at the bottom of the cylinder, let the valves s and c′ be both closed, and the valves s′ and c be opened, as represented in fig. 16. Steam will now be admitted through the open valve s′ and through the passage D′ below the piston, while the steam which has just driven the piston downwards, filling the cylinder above the piston, will be drawn off through the open valve c, and the exhausting pipe, leaving in the cylinder above the piston a vacuum. The piston will, therefore, be pressed upwards by the action of the steam below it, and will ascend with the same force as that with which it had descended.

Fig. 16.



The alternate action of the piston upwards and downwards may evidently be continued by opening and closing the valves alternately in pairs. Whenever the piston is at the top of the cylinder, as represented in fig. 15, the valves s and c′, that is, the upper steam valve and the lower exhausting valve are opened; and the valves c and s′, that is, the upper exhausting valve and the lower steam valve, are closed; and when the piston has arrived at the bottom of the cylinder, as represented in fig. 16, the valves c and s′, that is, the upper exhausting valve and the lower steam valve, are opened, and the valves s and c′, that is, the upper steam valve and the lower exhausting valve, are closed.

If these valves, as has been here supposed, be opened and closed at the moments at which the piston reaches the top and bottom of the cylinder, it is evident that they may be all worked by a single lever connected with them by proper mechanism. When the piston arrives at the top of the cylinder, this lever would be made to open the valves S and C′, and at the same time to close the valves S′ and C; and when it arrives at the bottom of the cylinder, it would be made to close the valves S and C′, and to open the valves S′ and C.

30. The methods of opening and closing the passages by means of lids slipping over them called slides, are those most generally used, and have infinitely various forms, although they differ one from another but little in the principle of their action. One of these expedients shown in fig. 17—18, will render the mode of their action easily understood. A B is a steam-tight case attached to the side of the cylinder; E F is a rod, which receives an alternate motion, upwards and downwards, from the eccentric, or from whatever other part of the engine is intended to move the slide. This rod, passing through a stuffing box, moves the slide G upwards and downwards. S is the mouth of the steam pipe coming from the boiler; T is the mouth of a tube or pipe leading to the condenser; H is a passage leading to the top, and I to the bottom, of the cylinder. In the position of the slide represented in fig. 17, the steam coming from the boiler through S passes through the space H to the top of the cylinder, while the steam from the bottom of the cylinder passes through the space I into the tube T, and goes to the condenser. When the rod E F is raised to the position represented in fig. 18, then the passage H is thrown into communication with the tube T, while the passage I is made to communicate with the tube S. Steam, therefore, passes from the boiler through I below the piston, while the steam which was above the piston, passing through H into T, goes to the condenser. Thus the single slide G performs the office of the four valves described in § 29.

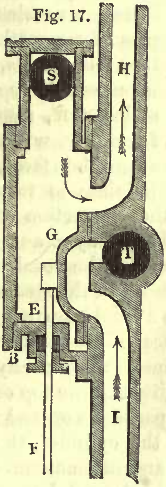


Fig. 17.

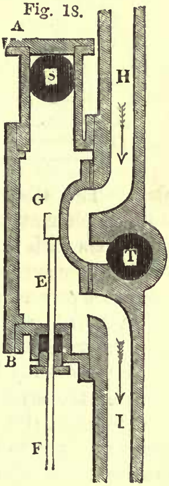
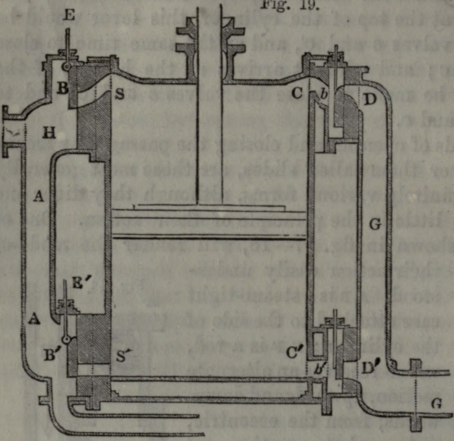


Fig. 18.

Fig. 19.



31. Another form of slides is shown in fig. 19. The steam pipe proceeding from the boiler to the cylinder is represented at A A, and it communicates with passages S and S′ leading to the top and bottom of the cylinder. These passages are formed in nozzles of iron or other hard metal cast upon the side of the cylinder. These nozzles present a smooth face outwards, upon which the slides B B′, also formed with smooth faces, play. The slides B B′ are attached by knuckle-joints to rods E E′, which move through stuffing-boxes, and the connection of these rods with the slides is such that the slides have play so as to detach their surfaces easily from the smooth surfaces of the nozzles when not pressed against these surfaces. The steam in the steam pipe A A will press against the backs of the slides B B′, and keep their faces in steam-tight contact with the smooth surfaces of the nozzles. These slides may be opened or closed by proper mechanism at any point of the stroke. When steam is to be admitted to the top of the cylinder, the upper slide is raised and the passage S opened; and when it is to be admitted to the bottom of the cylinder, the lower slide is raised and the passage S′ opened: and its communication with the top or bottom of the cylinder is stopped by the lowering of these slides respectively. On the other side of the cylinder are provided two passages C C′ leading to a pipe G, which is continued to the condenser. On this pipe are cast nozzles of iron or other metal presenting smooth faces towards the cylinder, and having passages D D′ communicating between the top and bottom of the cylinder respectively and the pipe G G leading to the condenser. Two slides *b b*′, having smooth faces turned from the cylinder, and pressing upon the faces of the nozzles D D′, are governed by rods playing through stuffing-boxes, in the same manner as already described. The faces of these slides being turned from the cylinder, the steam in the cylinder having free

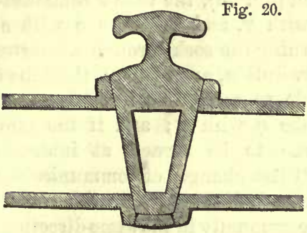
communication with them, has a tendency to keep them by its pressure in steam-tight contact with the surfaces in which the apertures leading to the condenser are formed. These two slides may be opened or closed whenever it is necessary.

When the piston commences its descent, the upper steam slide is raised, so as to open the passage S, and admit steam above the piston; and the lower exhausting slide *b′* is also raised, so as to allow the steam below the piston to escape through G, the other two passages S′ and C being closed by their respective slides. The slide which governs S is lowered at that part of the stroke at which the steam is intended to be cut off, the other slides remaining unchanged; and when the piston has reached the bottom of the cylinder, the lower steam slide opens the passage S′, and the upper exhausting slide opens the passage C, and at the same time the lower exhausting slide closes the passage C′. Steam being admitted below the piston through S′, and at the same time the steam above it being drawn away through the open passage C and the tube G, the piston ascends. When it has reached that point at which the steam is intended to be cut off, the slide which governs S′ is lowered, the other slides remaining unaltered, and the upward stroke is completed in the same manner as the downward.

These four slides may be governed by a single lever, or they may be moved by separate means. From the small spaces between the several slides and the body of the cylinder, it will be evident that the waste of steam by this contrivance will be very small.

32. The admission and escape of the steam is sometimes governed by cocks, more especially in engines constructed on a small scale. The most common form for cocks is that of a cylindrical or slightly conical plug (fig. 20), inserted in an aperture of corresponding magnitude passing across the pipe or passage which the cock is intended to open or close. One or more holes are pierced transversely in the cock, and when the cock is turned, so that these holes run in the direction of the tube, the passage through the tube is opened; but when the passage through the cock is placed at right angles to the tube, then the sides of the tube stop the ends of the passage in the cock, and the passage through the tube is obstructed. The simple cock is designed to open or close the passage through a single tube. When the cock is turned, as in fig. 21, so that the passage through the cock shall be at right angles to the length of the tube, then the passage

Fig. 20.



through the tube is stopped; but when the cock is turned from that position through a quarter of a revolution, as in fig. 22, then the passage through the cock takes the direction of the passage through the tube, and the cock is opened, and the passage through the tube unobstructed. In such a cock the passage may be more or less *throttled* by adjusting the position of the cock, so that a part of the opening in it shall be covered by the side of the tube.

Fig. 21.

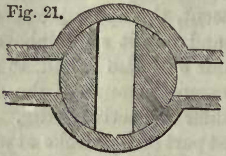
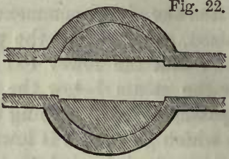
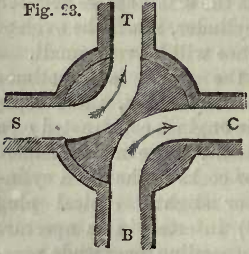


Fig. 22.



33. It is sometimes required to put one tube or passage alternately in communication with two others. This is accomplished by a *two-way cock*. In this cock the passage is curved, opening usually at points on the surface of the cock, at right angles to each other. When it is required to put four passages alternately in communication by pairs, a *four-way cock* is used. Such a cock has two curved passages (fig. 23), each similar to the curved passage in the two-way cock. Let S C B T be the four tubes which it is required to throw alternately into communication by pairs. When the cock is in the position (fig. 23), the tube S communicates with T, and the tube C with B. By turning the cock through a quarter of a revolution, as in fig. 24, the tube S is made to communicate with B, and the tube C with T; and if the cock continue to be turned at intervals through a quarter of a revolution, these changes of communication will continue to be alternately made. It is evident that this may be accomplished by turning the cock continually in the same direction.

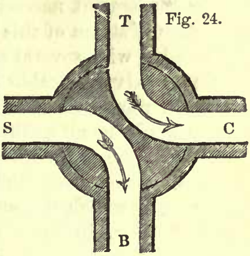
Fig. 23.



The four-way cock is sometimes used as a substitute for the valves or slides to conduct the steam to and from the cylinder. If S represent a pipe conducting steam from the boiler, C the exhausting pipe, T the tube which leads to the top of the cylinder, and B that which leads to the bottom, then when the cock is in the position (fig. 23), steam would flow from the boiler to the top of the piston, while the steam below it would be drawn off: and in the position (fig. 24), steam would flow from the boiler to the bottom of the piston, while the steam above it would be drawn off. Thus by turning the cock through a quarter of a revolution towards the termination of each stroke, the operation of the machine would be continued.

34. It will be understood from all that has been stated that the mechanical effect of the steam engine depends, other things being given, upon the excess of the pressure of the steam which impels the piston above the reaction of the steam which escapes at the end of the cylinder towards which the piston is moving. To whatever extent, therefore, this reaction is diminished, the efficacy of the engine will be increased.

Fig. 24.



Steam engines are resolved into two distinct classes, according to the way in which the steam escaping from the cylinder is disposed of, called non-condensing and condensing engines, or, more commonly, though less properly, high pressure and low pressure engines. The objection to the latter denomination being that, although non-condensing engines must necessarily be worked with high pressure steam, condensing engines need not be worked with low pressure steam, as will presently appear.

In the class of non-condensing or high pressure engines, the exhaustion pipes of the cylinder open into the atmosphere; in the condensing or low pressure engines, they lead to an apparatus in which the steam is *condensed*, the name given to the process of reconverting it into water by exposure to cold.

35. In non-condensing engines the exhausting pipe communicating with the external air, this air will, when the exhausting valve is open, have a tendency to rush into the cylinder, while the steam has, on the contrary, a tendency to rush out. If, in this case, the pressure of the steam were not greater than that of the atmosphere, its escape would be prevented by the counter pressure of the air, and as the pressure of the steam is the measure of its reaction against the piston, it follows that in this class of steam engine, the reaction on the piston must always be somewhat greater than the atmospheric pressure, which, as has been shown in vol. ii., p. 4, amounts on an average to 15lbs. per square inch.

Since, then, the piston of a non-condensing engine is subject, necessarily and constantly, to a reaction exceeding 15lbs. per square inch, the pressure of the steam by which it is impelled must greatly exceed 15lbs. per square inch. Thus a pressure of 30lbs. per square inch would give an effective pressure much less than 15lbs. per square inch, because, besides the reaction of the steam, the impelling power is resisted by friction. A pressure of 45lbs. per square inch would give an effective force amounting to less than 30lbs. per square inch, and so on.

Notwithstanding the disadvantage of this reaction on the piston, and the consequent necessity of providing a boiler suitable to the production of steam of this high pressure, non-condensing engines are attended with several countervailing advantages which render them not only preferable in certain cases to condensing engines, but which render them efficient where the adoption of condensing engines would be altogether impracticable.

36. In condensing engines, the exhausting pipes which proceed from the ends of the cylinder lead to a reservoir or vessel called a condenser, in which the steam, being exposed to cold, is reduced to water. Now, since a cubic foot of steam will, when re-converted into liquid, form only about a cubic inch of water, it is plain that by this process of condensation, efficiently conducted, the steam escaping from the cylinder may be considered as passing into a vacuum, and therefore not only is it not subject to the resistance of the atmosphere, but to no resistance whatever, except what may arise from the contracted dimensions of the exhausting pipe. The conversion of the steam into water being, moreover, almost instantaneous, the reaction attending its escape, small as it is, is only momentary, and affects the piston only at the commencement of the stroke, throughout the remainder of which it will be subject to no reaction whatever.

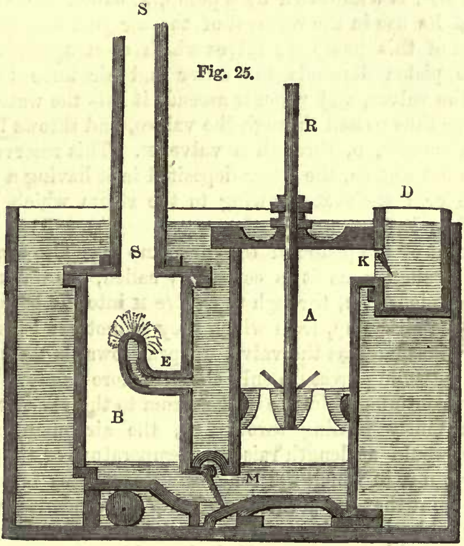
Thus it appears, that, in condensing engines the pressure of the steam which impels the piston instead of being subject, as in non-condensing engines, to a reaction exceeding 15 lbs. per square inch, is subject to scarcely any reaction at all; and consequently its pressure, to be effective, need not exceed a few pounds, say from 4 lbs. to 6 lbs. per square inch. It is for this reason that condensing engines have been commonly called low-pressure engines.

But although low-pressure steam *may* be used in this class of engines, and in most cases *is* used, it is not thus used exclusively or necessarily. Steam of any pressure, however high, may be worked in them, and the condensing apparatus will still render equal service. In certain applications of the engine, steam having a pressure several times greater than that of the atmosphere is worked with great advantage in engines constructed on this principle.

37. Since the condensing apparatus discharges such important functions, it will be useful to show its structure and arrangement, in connection with the piston and cylinder.

A section of such an apparatus is shown in fig. 25. A cistern, C C, is filled with cold water. Immersed in it is a metal vessel, B, called the condenser. A pipe, S S, connects this condenser with the exhausting pipe of the cylinder, of which S S may be

Fig. 25.



considered as the continuation. A jet-pipe, E, enters the condenser, and is bent upwards. It is terminated with a piece pierced with holes like the rose of a watering-pot, and the cold water of the cistern, C C, being pressed in through the pipe, E, is thrown up in the condenser, as shown in the figure. The steam, escaping from the cylinder along the pipe, S S, encounters this cold jet and is instantly condensed. Mixing with the cold water of the jet, it forms warm water, which collects in the bottom of the condenser.

If means were not provided for the removal of this water, the vessel B would soon become choked with it, so as to arrest the action of the apparatus.

38. But there is also another effect, which it is important to explain. Water as it commonly exists always contains more or less air fixed in or mingled with it. The air thus fixed in the water of the cistern, C C, is disengaged in greater or less quantity by the heat to which it is exposed when the steam is mixed with it in the vessel B. This air, rising through the tube, S S, offers more or less resistance to the escape of the steam, and reacts upon the piston to the detriment of the moving power. Its accumula-

tion, if not removed, would soon obstruct and altogether arrest the action of the machine.

This air, as well as the warm water deposited in the bottom of the condenser, is withdrawn by a pump, A, called the AIR-PUMP, because of its use in the removal of the air just mentioned. In the piston of this pump are valves which open upwards, so that when the piston descends the water and air force themselves through the valves, and when it ascends it lifts the water and air which have thus passed through the valves, and throws them into a small reservoir, D, through a valve, K. This reservoir, D, is called the hot cistern, the water deposited in it having a temperature more or less elevated, owing to the steam which has been condensed by it.

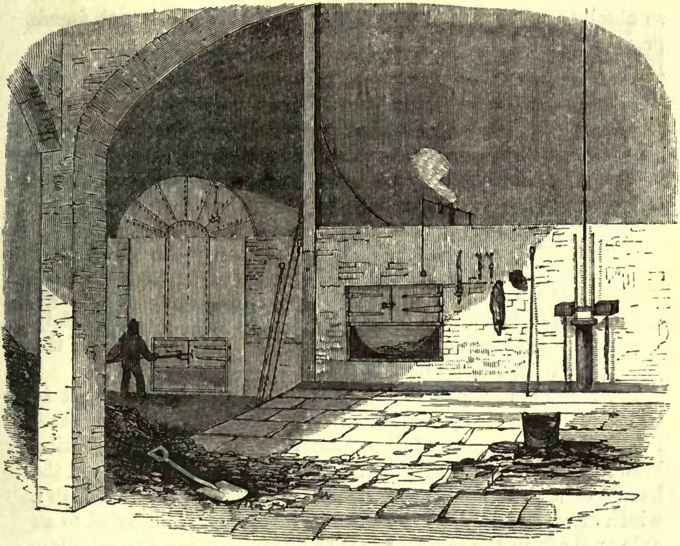
The ascent of the piston of the air-pump has also the effect of drawing by suction, as it is commonly called, the water and air from the condenser, B, through the valve M into the bottom of the barrel of the air-pump, from which they cannot get back into the condenser, inasmuch as the valve, M, opens towards the air-pump, and their returning pressure only closes it more firmly.

39. The continual affluence of the steam to the vessel B, and the water constantly passing through it, the air-pump, and the cistern, D, would at length raise the temperature of the water in the cistern, C C, in which the condensing apparatus is immersed, to such a point that the jet projected into the condenser would be no longer cold enough to condense the steam.

To prevent this a pump, called the cold-water pump, is provided, which throws into the cistern a sufficient quantity of cold water. This water is introduced near the bottom of the cistern, a waste-pipe being provided at the top by which the warm water, which always collects near the upper surface, flows off. In this way the temperature of the water in the cistern, C C, is kept sufficiently low, notwithstanding the heat proceeding from the condensing vessels.

40. To prevent the accumulation of warm water in the cistern, D, a pump called the hot-water pump is connected with it, by which the water is drawn off from it and transferred to the feeding apparatus of the boiler. Thus a part of the heat given out by the condensed steam, and which has already done duty in working the piston, is returned to the boiler to take another round of duty.

Thus it appears that the condensing apparatus consists of the cold cistern, C C, the cold-water pump which supplies it, the condenser, B, the air-pump, A, the hot cistern, D, and the hot-water pump, which draws the water from it.



FURNACE AT THE CITY SAW MILLS.

THE STEAM ENGINE.

CHAPTER III.

41. Comparative merits of the two kinds of engines.—42. Various modes of transmitting force.—43. Description of a factory engine.—44. The governor.—45. The eccentric.—46. The fly-wheel.—47. Parallel motion.—48. Barometer gauge.—49. How to compute the effective moving force of the piston.—50. Method not considered sufficiently accurate.—51. Indicator.—52. Mode of recording its positions.—53. Its application in finding effective force.—54. Watt's counter.—55. Conclusion.

41. THAT the advantages arising from the diminished reaction on the piston, produced by the condensation of the steam, are not altogether to be placed to the account of increased moving power, will be apparent when it is observed that no inconsiderable part of the power thus gained is absorbed by the cold-water pump, the air pump, and the hot-water pump, all of which are worked by the engine. Neither is the vacuum into which the piston moves,

so absolute as it might at first appear to be. It is not found practicable to keep the water in the condenser at a temperature lower than 100°, and at that temperature steam is evolved which has a pressure of about one pound per square inch, which, after all, will still react upon the piston.

In comparing, then, the non-condensing and condensing engine, it is apparent, that while the latter gives a much greater amount of moving power with the same rate of evaporation, and consequently with the same consumption of fuel, the former is vastly more simple in its mechanism, lighter in its weight, more inexpensive in its construction and maintenance, and much more portable.

42. From what has been explained, it will be understood how the piston-rod is made to move with any desired force alternately in one direction or other, through a space equal to the stroke of the piston, or, what is the same, to the length of the cylinder.

The manner in which this force is transmitted to the object to which the engine is applied, is extremely various. In some cases the end of the piston-rod is connected with that of a vibrating beam, to which a motion of oscillation is imparted like that of the handle of a pump. In other cases it is put in connection with a winch or crank, by which a motion of revolution is imparted to an axle or shaft, in the same manner as a man working at a windlass causes a rope to wind upon its axle. In other cases it is connected with a wheel, to which it imparts rotation, as in some forms of the locomotive engine. In short, the expedients by which the alternate force of the piston is applied to the particular work to be performed by the engine are so numerous, and differ so much one from another, that it would be quite impossible to give any general account which would include them.

43. To convey, however, some idea of one of the most common methods of transmitting the force of the piston, we shall take the case of the steam engine generally used to propel the machinery of the larger class of factories, a view of which is given in fig. 26. The several parts will be easily understood, after what has been stated, without further explanation.

C is the steam cylinder.

P, the steam piston.

V V′, the valves for admitting and withdrawing the steam, at each end of the cylinder.

R, the piston-rod of the air pump.

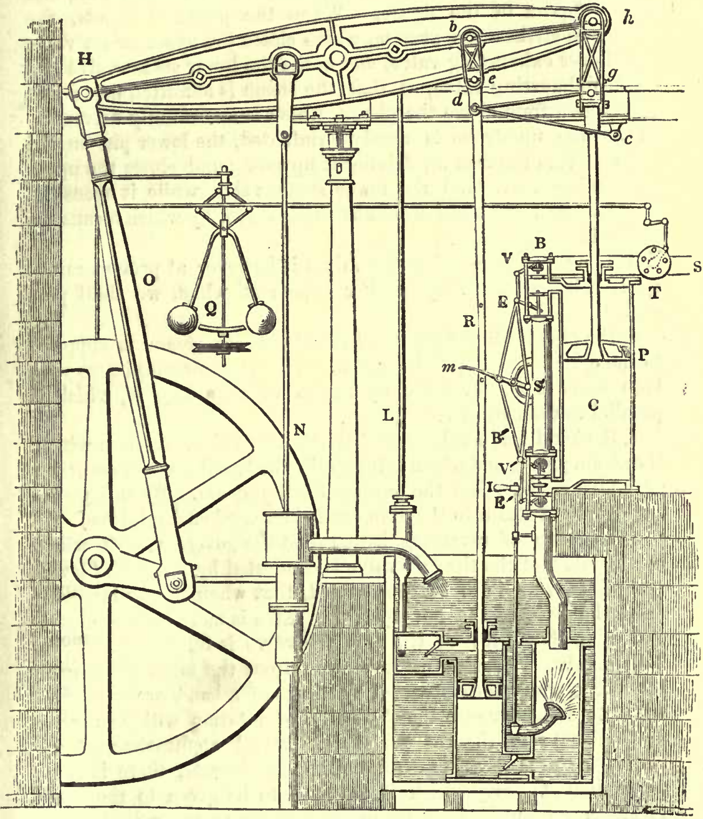
L, the piston-rod of the hot-water pump.

N, the piston-rod of the cold-water pump.

I, the handle of the cock by which the jet in the condenser is made to play with more or less force.

b, *d*, *g*, *c*, a system of jointed rods called the parallel motion, by means of which the motion of the beam in the arc of a circle is rendered compatible with that of the piston-rod in a straight line.

Fig. 26.



h, the pin on the end of the beam connected with the end of the piston-rod by the joint *h g*.

b, the pin on the beam connected with the piston-rod of the air pump by the joint *b d*.

H, the pin on the working end of the beam.

O, a rod called the connecting rod, by which the end H of the beam is connected with a crank or winch upon the main shaft, to which it is required to impart rotation.

m, a lever jointed to a system of rods by which the valves V V′ admitting and withdrawing the steam at the top and bottom of the cylinder are opened and closed. This lever *m* is acted upon by pins which project from the piston-rod of the air pump, and which appear in the figure. When the piston descends, the upper pin strikes the arm *m*, which closes the upper steam valve and lower exhausting valve, and opens the lower steam valve and upper exhausting valve, so that the steam is admitted below and withdrawn from above the piston, which is accordingly driven up. When the up-stroke is nearly terminated, the lower pin on the rod R strikes the arm *m*, driving it upwards, and closes the upper exhausting valve and the lower steam valve, while it opens the upper steam valve and lower exhausting valve, by which means the piston is driven down.

This method of working the valves is however at present rarely used, being replaced by another expedient which we shall presently describe.

S, the pipe leading from the boiler by which steam is supplied to the cylinder to impel the piston. This pipe communicates with both ends of the cylinder by means of a passage S′, which is parallel to the cylinder.

T, the handle of a valve called the throttle valve, which is within the steam pipe S, and which is turned by the handle, so as to contract or widen more or less the passage for the steam. By this means the supply of steam to the cylinder is increased or diminished.

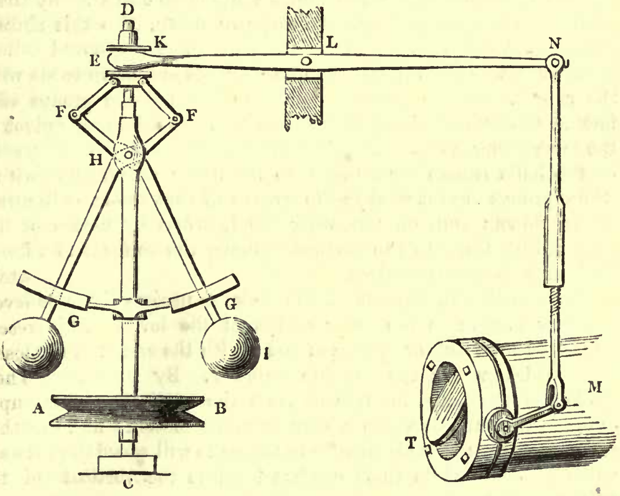
Q, a system of revolving balls called the governor, with which the handle T of the throttle valve is connected by a series of levers and joints, which are so constructed, that when the balls recede from the axis of the governor, the valve is more or less closed, and when they fall near the axis, the valve is fully open. These balls receive a motion of revolution from the main shaft upon which the crank is constructed by means of a band or by toothed wheels. In either case their velocity of rotation will be always proportionate to that of the shaft. In all applications of the engine to the purposes of manufacture and the arts, there is some determinate velocity which is required to be given to the shaft. If steam be supplied in too great quantity to the cylinder, the motion given to the shaft will be too rapid; and if it be supplied in too small quantity, the motion will be too slow.

Such irregularities of motion are prevented by the governor. The moment the motion begins to be too rapid, the centrifugal force produced by the revolution causes the balls to fly out, to recede from the axis, and to close more or less the throttle valve. If, on the contrary, the motion begins to be two slow, the balls fall in, approach the axis, and open the throttle valve. Thus every undue increase of speed diminishes the supply of steam, and moderates the velocity; and every undue decrease of speed increases the supply of steam, and augments the velocity. In this manner the action of the governor keeps the engine constantly moving at a regulated rate.

44. The manner in which the governor opens the throttle valve will be still more easily understood by the aid of fig. 27.

A small grooved wheel A B is attached to a vertical spindle supported in pivots or sockets C and D, in which it is capable of revolving. An endless cord works in the groove A B, and is carried over proper pulleys to the axle of the fly-wheel, where it likewise works in a groove. When this cord is properly tightened, the motion of the fly-wheel will give motion to the wheel A B, so that the velocity of the one will be subject to all the changes incidental to the velocity of the other. By this means the speed of the grooved wheel A B may be considered as representing the speed of the fly-wheel, and of the machinery which the axle of the fly-wheel drives.

Fig. 27.



It is evident that the same end might be obtained by substituting for the grooved wheel A B a toothed wheel, which might be connected by other toothed wheels, and proper shafts and axles with the axle of the fly-wheel.

A ring or collar E is placed on the upright spindle, so as to be capable of moving freely upwards and downwards. To this ring are attached by pivots two short levers, E F, the pivots or joints at E allowing these levers to play upon them. At F these levers are joined by pivots to other levers F G, which cross each other at H, where an axle or pin passes through them, and attaches them to the upright spindle C D. These intersecting levers are capable, however, of playing on this axle or pin H. To the ends G of these levers are attached two heavy balls of metal. The levers F G pass through slits in a metallic arc attached to the upright spindle, so as to be capable of revolving upon it. If the balls are drawn outwards from the vertical axis, it is evident that the ends F of the levers will be drawn down, and therefore the pivots E likewise drawn down. In fact, the angles E F H will become more acute, and the angles F E F more obtuse. By these means the sliding ring E will be drawn down. To this sliding ring E, and immediately above it, is attached a grooved collar, which slides on the vertical spindle upwards and downwards with the ring E. In the grooved collar are inserted the prongs of a fork K, formed at the end of the lever K L, the fulcrum or pivot of the lever being at L. By this arrangement, when the divergence of the balls causes the collar E to be drawn down, the fork K, whose prongs are inserted in the groove of that collar, is likewise drawn down; and, on the other hand, when by reason of the balls falling towards the vertical spindle, the collar E is raised, the fork K is likewise raised.

The ascent and descent of the fork K necessarily produce a contrary motion in the other end N of the lever. This end is connected by a rod, or system of rods, with the end M of the short lever which works the throttle valve T. By such means the motion of the balls, towards or from the vertical spindle, produces in the throttle valve a corresponding motion; and they are so connected that the divergence of the balls will cause the throttle valve to close, while their descent towards the vertical spindle will cause it to open.

These arrangements being comprehended, let us suppose that, either by reason of a diminished load upon the engine or an increased activity of the boiler, the speed has a tendency to increase. This would impart increased velocity to the grooved wheel A B, which would cause the balls to revolve with an accelerated speed. The centrifugal force which attends their motion would therefore give them a tendency to move from the axle, or to diverge. This would cause, by the means already explained, the throttle valve T to be partially closed, by which the supply of steam from the boiler to the cylinder would be diminished, and the energy of the moving power, therefore, mitigated. The undue increase of speed would thereby be prevented.

If, on the other hand, either by an increase of the load, or a diminished activity in the boiler, the speed of the machine was lessened, a corresponding diminution of velocity would take place in the grooved wheel A B. This would cause the balls to revolve with less speed, and the centrifugal force produced by their circular motion would be diminished. This force being thus no longer able fully to counteract their gravity, they would fall towards the spindle, which would cause, as already explained, the throttle valve to be more fully opened. This would produce a more ample supply of steam to the cylinder, by which the velocity of the machine would be restored to its proper amount.

45. The method of working the valves by means of pins projecting from the rod of the air pump has been in most cases superseded by an apparatus called an *eccentric*, by which the motion of the axle of the fly-wheel is made to open and close the valves at the proper times.

An eccentric is a metallic circle attached to a revolving axle, so that the centre of the circle shall not coincide with the centre round which the axle revolves. Let us suppose that G (fig. 28) is a square revolving shaft. Let a circular plate of metal, B D, having its centre at C, have a square hole cut in it corresponding to the shaft, G, and let the shaft, G, pass through this square aperture, so that the circular plate, B D, shall be fastened upon the shaft, and capable of revolving with it as the shaft revolves. The centre, C, of the circular plate will be carried round the centre, G, of the revolving shaft, and will describe round it a

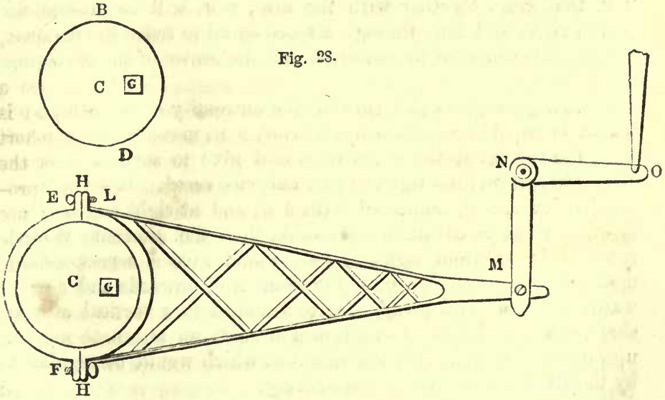


Fig. 28.

circle, the radius of which will be the distance of the centre, C, of the circular plate from the centre of the shaft. Such circular plate, so placed upon a shaft, and revolving with it, is *an eccentric.*

Let E F be a metallic ring, formed of two semicircles of metal screwed together at H, so as to be capable, by the adjustment of the screws, of having the circular aperture formed by the ring enlarged and diminished within certain small limits. Let this circular aperture be supposed to be equal to the magnitude of the eccentric, B D. To the circular ring, E F, let an arm, L M, be attached. If the ring, E F, be placed around the eccentric, and the screws, H, be so adjusted as to allow the eccentric to revolve within the ring, E F, then, while the eccentric revolves, the ring not partaking of its revolution, the arm, L M, will be alternately driven to the right and to the left, by the motion of the centre, C, of the eccentric as it revolves round the centre, G, of the axle. When the centre, C, of the eccentric is in the same horizontal line with the centre, G, and to the left of it, then the position of L M will be that which is represented in fig. 28; but when, after half a revolution of the main axle, the centre, C, of the eccentric is thrown on the other side of the centre, G, then the point, M, will be transferred to the right, to a distance equal to twice the distance C G. Thus, as the eccentric revolves within the ring, E F, that ring, together with the arm, L M, will be alternately driven right and left, through a space equal to twice the distance between the centre of the eccentric and the centre of the revolving shaft.

If we suppose a notch formed at the extremity of the arm, L M, which is capable of embracing a lever, N M, moveable on a pivot at N, the motion of the eccentric would give to such a lever an alternate motion from right to left, and *vice versâ.* If we suppose another lever, N O, connected with N M, and at right angles to it, forming what is called a bell-crank, then the alternate motion received by M, from right to left, would give a corresponding motion to the extremity, O, of the lever, N O, upwards and downwards. If this last point, O, were attached to a vertical arm or shaft, it would impart to such arm or shaft an alternate motion upwards and downwards, the extent of which would be regulated by the length of the levers respectively.

By such a contrivance the revolution of the shaft is made to give an alternate vertical motion of any required extent to a vertical shaft placed near the cylinder, which may be so connected with the valves as to open and close them. Since the upward and downward motion of this vertical shaft is governed by the alternate motion of the centre, C, to the right and to the left of the centre, G, it is evident that, by the adjustment of the eccentric upon the shaft, the valves may be opened and closed at any required position of the crank, and therefore at any required position of the piston in the cylinder.

Such is the contrivance by which the valves, whatever form may be given to them, are now almost universally worked in double-acting steam engines.

46. Notwithstanding the regulating influence of the governor, the motion of the engine would still be subject to a certain inequality, owing to the varying action of the connecting rod, O (fig. 26), on the crank. It will be quite evident that this action is most efficient when O is placed at right angles to the crank, which it is twice in every revolution, but that the more oblique it is to the crank the less efficient will be its action upon it.

Now this inequality is effaced very nearly, if not altogether, by means of a large and massive wheel of cast iron, called the FLY-WHEEL, which is keyed upon the axle of the crank so as to revolve with it, as shown in fig. 26. This wheel being well constructed, and nicely balanced on its axle, is subject to very little resistance from friction; any moving force which it receives it therefore retains, and is ready to impart such moving force to the main axle whenever that axle ceases to be driven by the power. When the crank, therefore, is in those positions in which the action of the power upon it is most efficient, a portion of the energy of the power is expended in increasing the velocity of the mass of matter composing the fly-wheel. As the crank approaches the dead points, that is the points where it is in the same straight line with the connecting rod, the effect of the moving power upon the axle and upon the crank is gradually enfeebled, and at these points vanishes altogether. The momentum which has been imparted to the fly-wheel then comes into play, and carries forward the axle and crank out of the dead points with a velocity very little less than that which it had when the crank was in the most favourable position for receiving the action of the moving power.

By this expedient, the motion of revolution received by the axle from the steam piston is subject to no other variation than just the amount of change of momentum in the great mass of the fly-wheel which is sufficient to extricate the crank twice in every revolution from the mechanical dilemma to which its peculiar form exposes it; and this change of velocity may be reduced to as small an amount as can be requisite by giving the necessary weight and magnitude to the fly-wheel.

47. The combination of jointed rods represented at *c d g b*, in fig. 26, called the parallel motion, constitutes one of the many inventions of Watt, which has always excited the greatest admi-

ration, by reason of the remarkable geometrical intuition which it manifested in one who was uninstructed in the advanced principles of geometrical analysis upon which the perfection of its action depends. Although this beautiful arrangement has been very generally superseded by others of greater simplicity, and of sufficient, though less, precision of action, it will not be uninteresting here to attempt a brief and popular explanation of the principles upon which its performance depends.

The end of the beam with which the top of the piston-rod is connected vibrating upon its centre, necessarily plays in a circular arc, the convexity of which is presented to the right in fig. 26. Now it is clear, that if the end *g* of the piston-rod were immediately jointed to this end of the beam, it would be bent towards the right through the convexity of the arc, while the beam moves from its highest or lowest position to the middle of its play, and that while it moves from the latter to the former position it will be deflected back towards the left. Now, the efficient performance of the engine absolutely requires that the piston-rod should not be exposed to any such alternate strain, but that it should be guided in a perfectly straight line in the direction of the axis of the cylinder; and this is precisely what the parallel motion accomplishes.

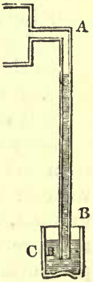
As we have just explained, the point *h* plays in an arc whose convexity is presented to the *right*. Now, the joint *c d*, or *link*, as it is called, moves upon a fixed centre, *c*, and consequently plays in an arc whose convexity is presented to the *left*, that is, contrary to the former. While the point *h* throws the upper end of the link *g h* to the right, by reason of the convexity of its play being on that side, the point *d* throws the lower end *g* to the left, by reason of its convexity being on the contrary side.

Now, the proportion of the lengths of the rods is so nicely adjusted, that the effect of the rod *c d* in throwing the point *g* to the left is exactly equal to the effect of the beam in throwing it to the right; and the consequence of this mutual compensation is, that the point *g*, to which the end of the piston-rod is jointed, is thrown neither to the right nor to the left, but is moved upwards and downwards in a straight line.

48. To be enabled to verify the efficiency of the engine and enforce a due economy of fuel, it is necessary to be provided with indicators, by which at all times the effective force of the piston can be ascertained. Now this effective force depends conjointly upon the pressure of the steam which moves the piston and the reaction of the uncondensed steam, and of the gases which the air pump may fail to withdraw from the condenser. Two mercurial gauges are accordingly provided for this purpose in all large stationary engines which are constructed on the condensing principle.

The force of steam which moves the piston is indicated by the steam gauge already described, and which is shown attached to the exposed end, K, of the boiler in fig. 7. The reaction of the uncondensed steam and gases is indicated by a gauge called the barometer gauge, inasmuch as it would be in fact a barometer if an absolute vacuum were produced before the piston. This gauge consists of a glass tube, A B (fig. 29), more than thirty inches long, and open at both ends, placed in an upright or vertical position, having the lower end B immersed in a cistern of mercury, C. To the upper end is attached a metal tube, which communicates with the condenser, in which a constant vacuum, or rather high degree of rarefaction, is sustained. The same vacuum must therefore exist in the tube A B, above the level of the mercury, and the atmospheric pressure on the surface of the mercury in the cistern C will force the mercury up in the tube A B, until the column which is suspended in it is equal to the difference between the atmospheric pressure and the pressure of the uncondensed steam. The difference between the column of mercury sustained in this instrument and in the common barometer, will determine the strength of the uncondensed steam, allowing a force proportional to one pound per square inch for every two inches of mercury in the difference of the two columns. In a well-constructed engine which is in good order, there is very little difference between the altitude in the barometer gauge and the common barometer.

Fig. 29.



49. To compute the force with which the piston descends, thus becomes a very simple arithmetical process. First, ascertain the difference of the levels of the mercury in the steam gauge; this gives the excess of the steam pressure above the atmospheric pressure. Then find the height of the mercury in the barometer gauge; this gives the excess of the atmospheric pressure above the uncondensed steam. Hence, if these two heights be added together, we shall obtain the excess of the impelling force of the steam from the boiler, on the one side of the piston, above the resistance of the uncondensed steam on the other side; this will give the effective impelling force. Now, if one pound be allowed for every two inches of mercury in the two columns just mentioned, we shall have the number of pounds of impelling pressure on every square inch of the piston. Then, if the number of square inches in the section of the piston be found, and multiplied by the number of pounds on each square inch, the force with which it moves will be obtained.

From what we have stated it appears that, in order to estimate the force with which the piston is urged, it is necessary to refer to both the barometer and the steam gauge. This double computation may be obviated by making one gauge serve both purposes. If the end C of the steam gauge (fig. 7), instead of communicating with the atmosphere, were continued to the condenser, we should have the pressure of the steam acting upon the mercury in the tube B A, and the pressure of the uncondensed vapour which resists the piston acting on the mercury in the tube B C. Hence the difference of the levels of the mercury in the tubes would at once indicate the difference between the force of the steam and that of the uncondensed vapour, which is the effective force with which the piston is urged.

50. Perfect as these expedients must appear, they have been deemed insufficient as indicators of an element so important as the economy of steam power. If, during the motion of the piston from end to end of the cylinder, the steam really acted upon it with an uniform force, and if the reaction against it were also uniform, then the steam and barometer gauges would give an exact measure of the effective power. But many causes co-operate in preventing such uniformity of action and reaction.

In the first place, the end of the cylinder from which the piston moves is never left in free communication with the boiler through the entire stroke. In all cases the steam is shut off by closing the steam valve before the stroke is completed, and if the engine works by expansion, which most engines do, the steam is shut off after a certain part of the stroke—such as three-fourths, two-thirds, a half, and sometimes even a third, or a fourth—has been made. In all such cases, the pressure on the piston after the steam has been shut off becomes less and less, as the steam in the cylinder expands by the advance of the piston.

Neither is the reaction uniform; for the condensation of the steam in the condenser is not absolutely instantaneous, though very rapid, but still less is the removal of the air and gases, which are fixed in the water injected to produce the condensation, instantaneous. The action of the air pump is gradual, and consequently the reaction on the piston, considerable at first, becomes gradually less and less towards the end of the stroke.

Now it is clear that, under these circumstances, the effective power of the piston, being always measured by the excess of the impelling force over the reaction, must vary continually from the beginning to the end of the stroke; and as the total effective force must consist of the aggregate of this varying action, it would seem to be a problem of the greatest practical difficulty to ascertain it.

51. Nevertheless, the inexhaustible resources of the genius of Watt, which surmounted so many other difficulties, did not shrink

before this; and produced an instrument of most felicitous perfection, called an Indicator, by which the object was perfectly and simply attained.

This contrivance consists of a cylinder of about $1\frac{3}{4}$ inch in diameter, and 8 inches in length. It is bored with great accuracy, and fitted with a solid piston moving steam-tight in it with very little friction. The rod of this piston is guided in the direction of the axis of the cylinder through a collar in the top, so as not to be subject to friction in any part of its play. At the bottom of the cylinder is a pipe governed by a stop-cock and terminated in a screw, by which the instrument may be screwed on the top of the steam cylinder of the engine. In this position, if the stop-cock of the indicator be opened, a free communication will be made between the cylinder of the indicator and that of the engine. The piston-rod of the indicator is attached to a spiral spring, which is capable of extension and compression, and which by its elasticity is capable of measuring the force which extends or compresses it in the same manner as a spring steel-yard or balance. If a scale be attached to the instrument at any point on the piston-rod to which an index might be attached, then the position of that index upon the scale would be governed by the position of the indicator piston in its cylinder. If any force pressed the indicator piston upwards, so as to compress the spring, the index would rise upon the scale; and if, on the other hand, a force pressed the indicator piston downwards, then the spiral spring would be extended, and the index on the piston-rod descend upon the scale. In each case the force of the spring, whether compressed or extended, would be equal to the force urging the indicator piston, and the scale might be so divided as to show the amount of this force.

Now let the instrument be supposed to be screwed upon the top of the cylinder of a steam engine, and the stop-cock opened so as to leave a free communication between the cylinder of the indicator below its piston and the cylinder of the steam engine above the steam piston. At the moment the upper steam valve is opened, the steam rushing in upon the steam piston will also pass into the indicator, and press the indicator piston upwards: the index upon its piston-rod will point upon the scale to the amount of pressure thus exerted. As the steam piston descends, the indicator piston will vary its position with the varying pressure of the steam in the cylinder, and the index on the piston-rod will play upon the scale, so as to show the pressure of the steam at each point during the descent of the piston.

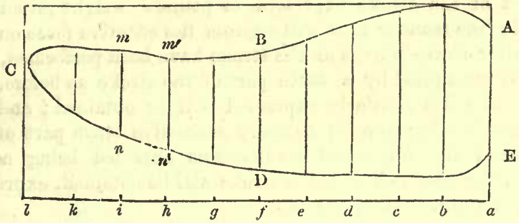
52. If it were possible to observe and record the varying positions of the index on the piston-rod of the indicator, and to refer each of these varying positions to the corresponding point of the

descending stroke, we should then be able to declare the actual pressure of the steam at every point of the stroke. But it is evident that such an observation would not be practicable. A method, however, was contrived by Mr. Southern, an assistant of Messrs. Boulton and Watt, by which this is perfectly effected. A square piece of paper, or card, is stretched upon a board, which slides in grooves formed in a frame. This frame is placed in a vertical position near the indicator, so that the paper may be moved in a horizontal direction backwards and forwards, through a space of fourteen or fifteen inches. Instead of an index, a pencil is attached to the indicator of the piston-rod: this pencil is lightly pressed by a spring against the paper above mentioned, and as the paper is moved in a horizontal direction, the pencil would trace upon it a line. If the pencil were stationary, this line would be straight and horizontal, but if the pencil were subject to a vertical motion, the line traced on the paper moved under the pencil horizontally would be a curve, the form of which would depend on the vertical motion of the pencil. The board thus supporting the paper is put into connection by a light cord carried over pulleys with some part of the parallel motion, by which it is alternately moved to the right and to the left. As the piston ascends or descends, the whole play of the board in the horizontal direction will therefore represent the length of the stroke, and every fractional part of that play will correspond to a proportional part of the stroke of the steam piston.

53. The apparatus being thus arranged, let us suppose the steam piston at the top of the cylinder commencing its descent. As it descends, the pencil attached to the indicator piston-rod varies its height according to the varying pressure of the steam in the cylinder. At the same time the paper is moved uniformly under the pencil, and a curved line is traced upon it from right to left. When the piston has reached the bottom of the cylinder, the upper exhausting valve is opened, and the steam drawn off to the condenser. The indicator piston being immediately relieved from a part of the pressure acting upon it, descends, and with it the pencil also descends; but at the same time the steam piston has begun to ascend, and the paper to return from left to right under the pencil. While the steam piston continues to ascend, the condensation becomes more and more perfect, and the vacuum in the cylinder, and therefore also in the indicator, being gradually increased in power, the atmospheric pressure above the indicator piston presses it downwards and stretches the spring. The pencil meanwhile, with the paper moving under it from right to left, traces a second curve. As the former curve showed the actual pressure of the steam impelling the piston in its descent, this latter

will show the pressure of the uncondensed steam resisting the piston in its ascent, and a comparison of the two will exhibit the effective force on the piston. Fig 30 represents such a diagram as would be produced by this instrument. A B C is the curve traced by the pencil during the descent of the piston, and C D E that during its ascent. A is the position of the pencil at the moment the piston commences its descent, B is its position at the middle of the stroke, and C at the termination of the stroke. On closing the upper steam valve and closing the exhausting valve, the indicator piston being gradually relieved from the pressure of the steam, the pencil descends, and at the same time the paper moving from left to right, the pencil traces the curve C D E, the gradual descent of this curve showing the progressive increase of the vacuum. As the atmospheric pressure constantly acts above the piston of the indicator, its position will be determined by the difference between the atmospheric pressure and the pressure of the steam below it; and therefore the difference between the heights of the pencil at corresponding points in the ascending and descending stroke will express the difference between the pressure of the steam impelling the piston in the ascent and resisting it in the descent at these points. Thus, at the middle of the stroke, the line B D will express the extent to which the spring governing the indicator piston would be stretched by the difference between the force of steam impelling the piston at the middle of the descending stroke, and the force of steam resisting it at the middle of the ascending stroke. The force, therefore, measured by the line B D will be the effective force on the piston at that point, and the same may be said of every part of the diagram produced by the indicator.

Fig. 30.



The whole mechanical effect produced by the stroke of the piston being composed of the aggregate of all its varying effects throughout the stroke, the determination of its amount is a matter of easy calculation by the measurement of the diagram supplied by the indicator. Let the horizontal play of the pencil from A to C be divided into any proposed number of equal parts, say ten: at the middle of the stroke, B D expresses the effective force on the piston; and if this be considered to be uniform through the tenth part of the stroke, as from *f* to *g*, then the number of pounds expressed by B D multiplied by the tenth part of the stroke expressed in parts of a foot, will be the mechanical effect through that part of the stroke expressed in pounds' weight raised one foot. In like manner *m n* will express the effective force on the piston after three-fourths of the stroke have been performed, and if this be multiplied by a tenth part of the stroke as before, the mechanical effect similarly expressed will be obtained; and the same process being applied to every successive tenth part of the stroke, and the numerical results thus obtained being added together, the whole effect of the stroke will be obtained, expressed in pounds' weight raised one foot.

54. By means of the indicator, the actual mechanical effect produced by each stroke of the engine can be obtained, and if the actual number of strokes made in any given time be known, the whole effect of the moving power would be determined. An instrument called a *counter* was also contrived by Watt, to be attached either to the working beam, or to any other reciprocating part of the engine. This instrument consisted of a train of wheel-work with governing hands, or indices moved upon divided dials, like the hands of a clock. A record of the strokes was preserved by means precisely similar to those by which the hands of a clock or timepiece indicate and record the number of vibrations of the pendulum or balance-wheel.

55. Such, then, is the machine, and such the principal expedients by which it has been adapted as a moving power of unparalleled importance and efficiency in all the industrial arts. In certain applications of the engine some of these provisions are unnecessary or inapplicable. In others supplementary expedients are required and supplied. Our present purpose, however, will be attained, if we have succeeded in rendering clearly intelligible the general principle upon which the machine as described above acts, and the special uses of the accessories that have been described. These being well understood, no great difficulty will be encountered in comprehending the mechanism and the action of any special form of engine.

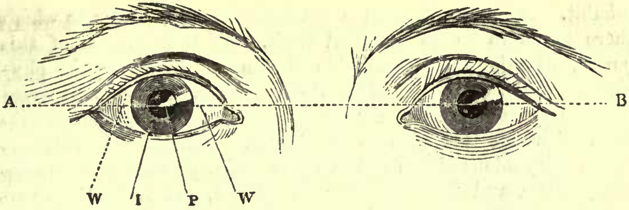


Fig. 1.

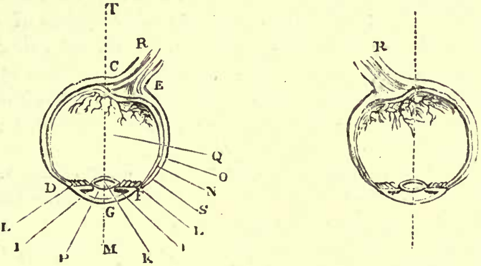


Fig. 2.

THE EYE.

CHAPTER I.

1. Pleasures and advantages of the power of vision.—2. Reasons why a knowledge of the structure and functions of the eye is desirable.—3. Description of the eye.—4. Sclerotica and cornea.—5. Aqueous humour, pupil, and iris.—6. Crystalline humour and ciliary processes.—7. Choroid.—8. Retina and vitreous humour.—9. Axis of the eye and optic nerve.—10. Numerical data.—11. Limits of the play of the eye. — 12. Achromatism of the eye. — 13-16. How vision is caused.—17. Conditions of perfect vision.—18. Distinctness of the image.—19. Parallel rays.—20, 21. Defects of vision and their remedies. — 22-24. Power of adaptation. — 25-29. Limits of this power.—30, 31.—Causes of defective vision.—32. Magnitude of the image on the retina.—33. Apparent magnitude defined.—34-37. Nature of its variation.—38-40. Diminutiveness of the pictures on the retina.—41. Sufficiency of illumination.

1. OF all the organs of sense, that to which we are most largely indebted is unquestionably THE EYE. It opens to us the widest and most varied range of observation. The pleasures and advantages we derive from it directly and indirectly have neither cessation nor bounds. It guides our steps through the world we

inhabit. It invests us with a space-penetrating power to which there seems to be no practical limit. By the exercise of this power, we enjoy the unspeakable pleasure of surveying the physical universe, consisting of countless myriads of worlds dispersed through the measureless abysses of space, worlds compared with most of which this of ours is of most diminutive dimensions. These stupendous globes roll in silent majesty round remote suns which warm and illuminate distant spheres, and collected in vast groups, are often presented to our eye as mere nebulous specks, but when viewed with high telescopic aid, blaze into stellar masses of the most dazzling splendour. System after system of worlds like our own are thus displayed before us, which, according to all analogy, are similarly peopled, and destined to fulfil like destinies in the moral economy of creations,—theatres of life and intelligence teeming with evidence of the incessant play of boundless power, wisdom, and goodness.

Although the eye, strictly speaking, is cognisant only of light and colours, yet from an habitual comparison of combinations and tints of colour with the forms of bodies, as ascertained by the sense of touch, we are enabled, with the greatest facility, promptitude, and precision, to recognise by the sight, the forms, magnitudes, motions, distances, and positions, not only of the objects which surround us, and which we can approach, but also of those constituting the material universe, which are inaccessible.

This vast range of observation, however, great as it is, forms but a small part of the sources of pleasure and advantage supplied by this organ. We have, besides, the inestimable advantages and the great moral powers which arise from the ability it bestows upon us to acquire knowledge through the study of books. It enables us to converse with and derive instruction from the most learned, the most wise, and the most virtuous of our own and all former ages; and although those who have the misfortune to be deprived of this important organ, can, to some small extent, replace it by the ear, aided by the eye of another; yet this, and all other expedients contrived for their relief, supply results infinitely small and insignificant compared with those which are obtained by the organ itself.

2. The eye, considered in itself apart from its uses, is a most interesting and instructive object. It affords beyond comparison the most beautiful example of design, structure, and contrivance, that is to be found in the animal economy. Nowhere do we find so remarkable an adaptation of means to an end, of means consisting of the most profound combination of scientific principles, and an end manifesting the operation of a will directed by the most boundless beneficence.

This organ is, for these reasons, a subject of inquiry and exposition, which must be regarded with the most lively interest by every one, whatever be his station, who is endowed with the least understanding or reflection. But besides the general considerations here developed, it is also to be remembered that, without a previous knowledge of the structure and functions of the eye, it is impossible to comprehend the use and application of the innumerable optical instruments which have been invented to aid its defects, whether natural or accidental; to repair the ravages of time, and to supply to age a renovated and re-invigorated organ of vision; to replace the diseased optical membrane removed by the knife of the surgeon, and thus restore sight where absolute blindness had ensued; to bring within the range of accurate vision objects rendered indistinctly visible, or altogether invisible, either by reason of their remoteness or minuteness. These admirable instruments can be easily rendered intelligible, provided a general knowledge of the structure and functions of the eye be first obtained, but not otherwise.

We purpose, therefore, to devote the present tract to a popular and simple exposition of the eye, and more particularly, the human eye.

3. The eyes, as they exist in the human species, have the form, as is well known, of two spheres, each about an inch in diameter, which are surrounded and protected by strong bony sockets placed on each side of the upper part of the nose. The external coating of these spheres is lubricated by a fluid secreted in adjacent glands, and spread upon them from time to time by the action of the eye-lids in winking.

The eye-balls are moved by muscles connected with them within the socket upon the principle known in mechanics as the ball and socket joint.

A front view of the eyes and surrounding parts is shown in fig. 1, a section of them made by a horizontal plane through the line A B, which passes through the centre of the front of the eye-balls, being shown in fig. 2 (see p. 49).

4. The external coating C D F E consists of a strong and tough membrane, called the *sclerotica*, or sclerotic coat. A part of this membrane is visible when the eye-lids are open at W, and is called the *white of the eye*. In this part of the eye-ball there is a circular opening, covered by a thin and perfectly transparent shell D G F, called the *cornea*. This cornea is more convex than the general surface of the eye-ball, and may be compared to a watch-glass. It is connected round its edge with the sclerotica, which differs from it, however, both in colour and opacity, the sclerotica being white and opaque, while the cornea is perfectly colourless

and transparent. The thickness of the cornea is everywhere the same.

The cornea covers that part of the front of the eye which is coloured, and is terminated round the coloured part at the commencement of the white of the eye.

5. Within the cornea is a small chamber filled with a transparent liquid, called the *aqueous humour*, partially divided by a thin annular partition I, called the iris, in the centre of which is a circular aperture P, called the *pupil*. The *iris* is a membraneous substance varying in colour in different individuals, which gives the peculiar colour to the eye. The pupil presents the appearance of a black spot in the centre of the coloured part. A front view of the iris and pupil is given at I and P, and a section is indicated by the same letters in fig. 2.

6. The membrane containing the aqueous humour is terminated at its posterior part by a substance in the form of a double convex lens, which contains another transparent liquid, called the *crystalline humour*. This lens K is somewhat greater in diameter than the pupil, and is supported by a ring of muscles, called the *ciliary processes* (represented at L), in such a position that its axis passes through the centre of the pupil.

Thus the crystalline and the ciliary processes, with the cornea, include the membrane containing the aqueous humour.

7. Within the sclerotica is a second coat N, called the *choroid.* This is a vascular membrane which lines the internal surface of the sclerotic coat, and which terminates in front in the ciliary processes, by which the crystalline lens is set in it in the same manner as the cornea is set in the sclerotic coat.

Some anatomists maintain that the iris is only a continuation of the choroid, and that the cornea is a continuation of the sclerotic coat, which there becomes transparent. The inner surface of this choroid coat is covered with a slimy pigment of an intensely black colour, by which the reflection of the light which enters the eye is prevented.

8. A third coat, represented at O, called the *retina*, from the resemblance of its structure to network, lines this black coating.

The internal chamber Q of the eye-ball is filled with a transparent liquor, called the *vitreous humour*, which is included in a membraneous capsule, called the hyaloid.

Thus between the cornea and the posterior surface of the eye there are three successive humours; the aqueous, contained by the cornea; the crystalline, contained by the crystalline lens; and the vitreous, which fills the inner and larger chamber of the eye-ball.

9. A straight line M T passing through the centre of the cornea,

coinciding with the axis of the crystalline lens, and through the centre of the eye-ball, is called the *optical axis*, or the *axis of the eye.*

At a point of the posterior surface of the eye-ball between the optical axis M T and the nose, the sclerotic coat is formed into a tube, which leads backwards and upwards to the brain. This tube contains within it the *optic nerve*, which at the point C E, where it enters the eye-ball, spreads out over the inner surface of the choroid and forms the retina, and includes the *hyaloid capsule* containing the vitreous humour.

The retina must therefore be regarded as nothing more than the continuation and diffusion of the optic nerve.

The retina, which in dissection admits of being easily separated from the choroid, is absolutely transparent, so that the light or colours which enter the inner chamber of the eye are not intercepted by it, but penetrate it as they would any other thin and perfectly transparent substance, and are only arrested by the black coating spread upon the choroid.

10. The following are the average numerical data connected with the eye:—

	100ths of an inch.
Radius of sclerotic coating	39 to 43
Radius of cornea	28 — 32
External diameter of iris	43 — 47
Diameter of pupil	12 — 28
Thickness of cornea	4
Distance of pupil from centre of cornea	8
Distance of pupil from centre of crystalline	4
Radius of anterior surface of crystalline	28 — 39
Radius of posterior surface of crystalline	20 — 24
Diameter of crystalline	39
Thickness of crystalline	30
Length of optic axis	87 — 95

11. The limits of the play of the eye-ball are as follows:—The optic axis can turn in the horizontal plane through an angle of 60° towards the nose, and 90° outwards, giving an entire horizontal play of 150°. In the vertical direction it is capable of turning through an angle of 50° upwards and 70° downwards, giving a total vertical play of 120°.

12. When an image of any object is formed by a lens composed of a single piece of glass or other transparent substance, it is always tinged more or less at its edges with the prismatic colours, giving it a sort of iridescence. This constituted a defect of the telescope, which seemed so irremediable that many astronomers had recourse by preference to reflectors, in which no such effect is produced. At length it was discovered that this defect could be completely

removed by lenses, composed of two species of glass, having different refracting powers, and whose curvatures are mutually adapted according to principles established in optics.

Now, it is a curious and highly interesting fact, that the eye, which, as we know, is entirely free from this defect, owes its perfection in this respect to the application of precisely the same optical principle in its structure, so that if the first inventors of the telescope had only thought of copying more closely the structure of the eye, they would have discovered sooner the principle of ACHROMATISM, the name given to this precious quality of lenses, from two Greek words, signifying the absence of colour.

13. The structure of the eye being thus understood, it will be easy to explain the effect produced within it by luminous or illuminated objects placed before it.

Let us suppose rays of light proceeding from any luminous object, such as the sun, incident upon that part of the eye-ball which is left uncovered by the open eye-lids.

Those rays which fall upon the white of the eye, W, fig. 1, render visible that part of the eye-ball. Those rays which fall upon the cornea pass through it. The exterior rays fall upon the iris, by which they are reflected, and render it visible. The internal rays pass through the pupil, are incident upon the crystalline, which, being transparent, is also penetrated by them, from which they pass through the vitreous humour, and finally reach the posterior surface of the inner part of the eye, where they penetrate the transparent retina, and are received by the black surface of the choroid, upon which they produce an illuminated spot.

The aqueous humour being more dense than the external air, and the surface of the cornea, which includes it, being convex, rays passing from the air into it will be rendered by a general law of optics more convergent, or less divergent.

In like manner, the anterior surface of the crystalline lens being convex, and that humour being more dense than the aqueous, a further convergent effect will be produced.

Again, the posterior surface of the crystalline being convex towards the vitreous humour, and this latter humour being less dense than the crystalline, another convergent effect will take place. These rays passing successively through these three humours, are rendered at each surface more and more convergent.

14. If an object be placed before the eye, pencils of rays will proceed from it, and penetrate the successive humours; and if these pencils be brought to a focus at the posterior surface, an inverted image of the object will be formed there, exactly as it would be formed by lenses composed of any transparent media

whose refracting powers would correspond with each of the humours.

15. That this phenomenon is actually produced, may be rendered experimentally manifest by taking the eye-ball of an ox recently killed, and dissecting the posterior part, so as to lay bare the choroid. If the eye thus prepared be fixed in an aperture in a screen, and a candle be placed before it at a distance of eighteen or twenty inches, an inverted image of the candle will be seen through the retina, as if it were produced upon ground glass or oiled paper.

16. It appears, then, that the immediate cause of vision, and the immediate object of perception, is the image thus produced by means of the refracting powers of the humours of the eye.

17. In order, therefore, to perfect vision, the following conditions must be fulfilled:—

1°. The image must be perfectly distinct.

2°. It must have sufficient magnitude.

3°. It must be sufficiently illuminated.

4°. It must continue on the retina for a sufficient length of time.

Let us examine the circumstances which affect these conditions.

18.—1°. Distinctness of the image.

The image formed on the retina will be distinct or not, according as the pencils of rays proceeding from each point of the object placed before the eye, are brought to an exact focus on the retina or not. If they be not brought to an exact focus on the retina, their focus will be a point beyond the retina, or within it. In either case, the rays proceeding from any part of the object, instead of forming a corresponding point on the retina, will form a spot of greater or less magnitude, according to the distance of the focus of the pencil from the retina, and the assemblage of such luminous spots will form a confused picture of the object. This deviation of the foci of the pencils from the retina is caused by the refracting powers of the eye being either too feeble or too strong. If the refracting powers be too feeble, the rays are intercepted by the retina before they are brought to a focus; if they be too strong, they are brought to a focus before they arrive at the retina.

19. The objects of vision may be distributed into two classes, in relation to the refracting powers of the eye: 1st, Those which are at so great a distance from the eye, that the pencils proceeding from them may be regarded as consisting of parallel rays; 2ndly, Those which are so near that their rays have sensible divergence.

It has been stated that the diameter of the pupil varies from $\frac{1}{8}$ to $\frac{1}{4}$ an inch in magnitude, the variation depending upon a power of dilatation and contraction with which the iris is endued. Taking that diameter at its greatest magnitude of a quarter of an inch, pencils proceeding from an object placed at the distance of three feet would have an extreme divergence amounting to less than half a degree; and if the pupil be in its most contracted state when its diameter is only the one-eighth of an inch, then the divergence of the pencils proceeding from such an object would amount to about fifteen minutes of a degree. It may therefore be concluded, that pencils proceeding from all objects more distant from the eye than two or three feet, may be regarded as consisting of parallel rays.

20. If the refracting power of the humours of the eye be so feeble that rays proceeding from such objects, and which enter the eye in parallel directions, are not rendered sufficiently convergent to come to a focus on the retina, or on the contrary, are so strong as to bring them to a focus before they arrive at the retina, the image produced upon the retina will be confused from the cause just explained.

21. The remedy for such a defect in vision is supplied by the properties of convex and concave lenses.

If the eye possess too little convergent power, a convergent or convex lens is placed before it, which, receiving the parallel pencils, renders them convergent when they enter the pupil, and this enables the eye to bring them to a focus on the retina, provided the power of the lens be equal to the deficient convergence of the eye.

If, on the other hand, the convergent power of the eye be too great, so that the parallel rays are brought to a focus before arriving at the retina, a divergent or concave lens is placed before the eye, by means of which parallel pencils are rendered divergent before they enter the pupil; and the power of the lens is so adapted to the convergent power of the eye, that the rays shall be brought to a focus on the retina.

The two opposite defects of vision here indicated are generally called, the one *weak-sightedness* or *far-sightedness*, and the other *near-sightedness*.

If the objects of vision be placed so near the eye that the rays composing the pencils which proceed from them have sensible divergence, then the foci of these rays within the eye will be at a distance from the optical centre greater than the principal focus, which is the name given to the focus of parallel rays. If, therefore, in this case, the principal focus fall upon the retina, the focus of rays proceeding from such near objects would fall beyond it, and consequently the image on the retina would be indistinct.

22. It follows, therefore, that eyes which see distant objects at the greater class of distances would see indistinctly all objects at less distances, unless there were in the eye some means of self-adjustment, by which its convergent power may be augmented. Such means of self-adjustment are provided, which operate within certain limits, by which we are enabled so to accommodate the eye to the divergence of the pencils proceeding from near objects, that the same eyes which are capable of seeing distinctly objects so distant as to render the rays of the pencils sensibly parallel, are also capable of seeing with equal distinctness objects at distances varying from ten to twelve inches and upwards.

23. By what means the convergent power of the humours is thus varied is not certainly known, but that such means of self-adjustment exist may be proved by the following experiment:—

Let a small black spot be made upon a thin transparent plate of glass, and let it be placed at a distance of about twelve inches from the eye. If the eye be directed to it, the spot will be seen as well as distant objects visible through the glass. Let the attention be earnestly directed to the black spot, so that a distinct perception of its form may be produced. The objects visible at a distance will then be found to become indistinct.

But if the attention be directed more to the distant objects, so as to obtain a distinct perception of them, the perception of the black spot on the glass will then become indistinct. It is evident, therefore, that when the eye accommodates itself so as to form upon the retina a distinct image of an object at twelve inches distance, the image produced by objects at great distances will become indistinct; and that, on the other hand, when the eye so accommodates itself as to render the image produced on the retina by distant objects distinct, the image produced by an object at two inches distance will become indistinct.

24. It is evident, therefore, that the power of the eye to refract the pencils of light incident upon it, is to a certain extent under the control of the will; but by what means this change in the refracting power of the organ is made is not so apparent. Various hypotheses have been advanced to explain it. According to some, the form of the eye-ball, by a muscular action, is changed in such a manner as to increase the length of the optic axis, and thus to remove the posterior surface of the retina to a greater distance from the crystalline, when it is necessary to obtain a distinct view of near objects; and, on the contrary, to elongate the transverse diameter of the eye, and shorten the optic axis so

as to bring the retina closer to the crystalline, when it is desired to obtain a distinct view of distant objects.

According to others, this change of form is only effected in the cornea, which being rendered more or less convex by a muscular action gives a greater or less convergent power to the aqueous humour.

According to others, the eye accommodates itself to different distances by the action of the crystalline, which is moved by the ciliary processes either towards or from the cornea, thus transferring the focus of rays proceeding from it within a certain limit of distance to and from the retina; or, by a similar action of the ciliary processes, the crystalline lens may be supposed to be rendered more or less convex, and thus to increase or diminish its convergent power.

25. Whatever be the provisions made in the organisation of the eye, by which it is enabled to adapt itself to the reception of divergent pencils proceeding from near objects, the power with which it is thus endued has a certain limit. Thus eyes, which see distinctly distant objects, and which therefore bring parallel rays to a focus on the retina in their ordinary state, are not capable of seeing distinctly objects brought nearer to them than ten or twelve inches. The power of accommodating the vision to different rays is therefore limited to a divergence not exceeding that which is determined by the diameter of the pupil compared with a distance of ten or twelve inches. Now, as the diameter of the pupil is most contracted when the organ is directed to such near objects, we may assume it at its smallest magnitude at one-eighth of an inch, and therefore the divergence of a pencil proceeding from a distance of twelve inches would be $\frac{1}{96}$th, and the angle of divergence would therefore be very nearly half a degree.

It may, therefore, be assumed that eyes adapted to the vision of distant objects are in general incapable of seeing distinctly objects from which pencils have greater divergence than this, or which is the same, objects placed at less than ten or twelve inches from the eye.

26. In the case of eyes whose convergent power is too feeble to bring pencils proceeding from distant objects to a focus on the retina, they will be in a still greater degree inadequate to bring pencils to a focus which diverge from near objects; and consequently such eyes will require to be aided, for near as well as distant objects, by the interposition of convergent lenses. It would, however, be necessary to provide lenses of different convergent powers for distant and near objects, the latter requiring a greater convergent power than the former; and in general the nearer the objects viewed, the greater the convergent power required from the lens.

27. In the case of eyes whose convergent power is so great as to bring pencils proceeding from distant objects to a focus short of the retina, and which therefore, for such distant objects, require the intervention of divergent lenses, distinct vision will be attained without the interposition of any lens, provided the object be placed at such a distance that the divergence of the pencils proceeding from it shall be such that the convergent power of the eye bring them to a focus on the retina.

Hence it is that eyes of this sort are called *short-sighted*, because they can see distinctly such objects only as are placed at the distance which gives the pencils proceeding from them such a divergence, that the convergent power of the eye would bring them to a focus on the retina.

28. If it be desired to ascertain the focal length of the divergent lens which such an eye would require to see distant objects distinctly, it is only necessary to ascertain at what distance it is enabled to see distinctly the same class of objects without the aid of a lens. A lens having a focal length equal to this distance will enable the eye to see distant objects distinctly, because such a lens would give the parallel rays a divergence equal to the divergence of pencils proceeding from a distance equal to its focal length.

29. Persons are said to be more or less near-sighted, according to the distance at which they are enabled to see objects with perfect distinctness, and they accordingly require, to enable them to see distant objects distinctly, diverging lenses of greater or less focal length.

As persons who are enabled to see distant objects distinctly have the power of accommodating the eye so as to see objects at ten or twelve inches' distance, so short-sighted persons have a similar power of accommodation, but within proportionally smaller limits. Thus a short-sighted person will be enabled to see distinctly objects placed at distances from the eye varying from four or five inches upwards, according to the degree of short-sightedness with which he is affected.

30. The two opposite defects of vision which have been mentioned, arising from too great or too little convergent power in the eye, may arise, either from a defect in the quality of the humours or in the form of the eye. Thus near-sightedness may arise from too great convexity in the cornea or in the crystalline, or it may arise from too great a difference of density between the aqueous humour and the crystalline, or between the crystalline humour and the vitreous, or both of them; or, in fine, it may arise from defects both of the form and of the relative densities of the humours.

31. In a certain class of maladies incidental to the sight, the humours of the eye lose in a greater or less degree their trans-

parency, and the crystalline humour is more especially liable to this. In such cases vision is sometimes recovered by means of the removal of the crystalline humour, in which case the organ is reduced to two humours, the aqueous and the vitreous ; but as the eye owes in a greater degree to the crystalline than to the other humours the convergent power, it is necessary in this case to supply the place of the crystalline by a very strong convergent lens placed before the eye.

32.—2°. MAGNITUDE OF THE IMAGE ON THE RETINA.

In order to obtain a perception of any visible object, it is not enough that the image on the retina be distinct, it must also have a certain magnitude.

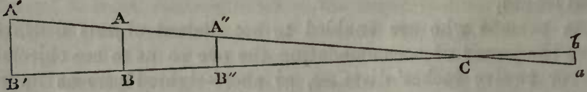
Let us suppose that a white circular disk, one foot diameter, is placed before the eye at a distance of $57\frac{1}{2}$ feet.

The axes of the pencils of rays proceeding from such disk to the eye will be included within a cone, whose base is the disk, and whose vertex is in the centre of the eye.

These axes, after intersecting at the centre of the eye, will form another cone, whose base will be the image of the disk formed upon the retina. The common angle of the two cones will in this case be 1°.

Let A B (fig. 3), be the diameter of the disk. Let C be the centre of the eye, and let $b\ a$ be the diameter of the image on the retina. It is clear, from the perfect similarity of the triangles A C B and a C b, that the diameter of the image $b\ a$ will have to the diameter of the object B A the same proportion as the distance a C of the retina from the centre C has to the distance A C of the object from the same centre. Therefore in this case, since one-half the diameter of the eye is but half an inch, and the distance A C is in this case supposed to be $57\frac{1}{2}$ feet, the magnitude of the diameter $b\ a$ of the image on the retina will be found by the following proportion :—

Fig. 3.



$$a\,b : \text{A B} : : \tfrac{1}{2} : 57\tfrac{1}{2} \times 12 = 690,$$

Therefore we have

$$a\,b = \frac{\frac{1}{2} \times \text{A B}}{690} = \frac{6}{690} = \frac{1}{115}.$$

The total magnitude, therefore, of the diameter of the image on the retina would in this case be the $\frac{1}{115}$th part of an inch; yet such is the exquisite sensibility of the organ, that the object is in this case distinctly visible.

If the disk were removed to twice the distance here supposed, the angle of the cone C would be reduced to half a degree, and the diameter of the image on the retina would be reduced to one-half its former magnitude, that is to say, to the $\frac{1}{230}$th part of an inch. If, on the other hand, the disk were moved towards the eye, and placed at half its original distance, then the angle C of the cone would be 2°, and the diameter of the picture on the retina would be double its first magnitude, that is to say, the $\frac{2}{115}$th of an inch.

In general, it may therefore be inferred that the magnitude of the diameter of the picture on the retina is increased or diminished in exactly the same proportion as the angle of the cone C, formed at the centre of the eye, is increased or diminished.

33. This angle is called the visual angle or apparent magnitude of the object; and when it is said that a certain object subtends at the eye a certain angle, it is meant that lines drawn from the extremities of such object to the centre of the eye form such angle.

The *apparent magnitude* of an object must not be confounded with its apparent superficial magnitude, the term being invariably applied to its *linear magnitude.* The apparent superficial magnitude varies in proportion to the square of the apparent magnitude.

Thus, for example, when the disk A B is removed to double its original distance from the eye, the apparent magnitude, or the angle C, is diminished one-half, and consequently the diameter *a b* of the picture on the retina is also diminished one-half; and since the diameter is diminished in the ratio of 2 to 1, the superficial magnitude of the image, or its area, will be diminished in the proportion of 4 to 1.

34. It is clear from what has been stated also, that when the same object is moved from or towards the eye, its apparent magnitude varies inversely as its distance; that is, its apparent magnitude is increased in the same proportion as its distance is diminished, and *vice versâ.*

It is easy to perceive that the objects which are seen under the same visual angle will have the same apparent magnitude. Thus let A′ B′ (fig. 3), be an object more distant than A B, and of such a magnitude that its highest point A′ shall be in the continuation of the line C A, and its lowest point B′ in the continuation of the line C B. The apparent magnitude of A′ B′ will then be measured by the angle at C. This angle will therefore at the same time represent the apparent magnitude of the object A B and of the object A′ B′. It is evident that an eye placed at C will see every point of the object A B upon the corresponding points of the object

A′ B′; so that if the object A B were opaque, and of a form similar to the object A′ B′, every point of the one would be seen upon a corresponding point of the other. In like manner, if an object A″ B″ were placed nearer the eye than A B, so that its highest point may lie upon the line C A, and its lowest point upon the line C B, the object being similar in form to A B, would appear to be of the same magnitude. Now it is evident that the real magnitudes of the three objects A″ B″, A B, and A′ B′, are in proportion to their respective distances from the eye; A′ B′ is just so much greater than A B, and A B than A″ B″, as C B′ is greater than C B, and as C B is greater than C B″.

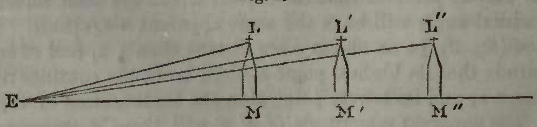
Thus it appears that if several objects be placed before the eye in the same direction at different distances, and that the real linear magnitudes of these objects are in the proportion of their distances, they will have the same apparent magnitude.

35. A striking example of this principle is presented by the case of the sun and moon. These objects appear in the heavens equal in size, the full moon being equal in apparent magnitude to the sun. Now it is proved by astronomical observation that the real diameter of the sun is, in round numbers, four hundred times that of the moon; but it is also proved that the distance of the sun from the earth is also, in round numbers, four hundred times greater than that of the moon. The distances, therefore, of these two objects being in the same proportion as their real diameters, their visual or apparent magnitudes are equal.

36. It is evident from what has been explained, that objects which have equal apparent magnitudes, and are therefore seen under equal visual angles, will have pictures of equal magnitude on the retina, a fact which proves that the visual angle is the measure of the apparent magnitude.

37. If the same object be moved successively to increasing distances, its apparent magnitude will be diminished in the same proportion, exactly as its distance from the eye is increased. Thus, if L M (fig. 4), be such an object, its apparent magnitude at the distance E M will be measured by the angle L E M, at the distance E M′ by the angle L′ E M′, and at the distance E M″ by the angle L″ E M″; and when the actual magnitude L M bears a

Fig. 4.



small proportion to the distance, it is shown by the principles of geometry that the angle $L'EM'$ is less than the angle LEM in the same proportion as EM' is greater than EM, and that the angle $L''EM''$ is less than LEM in the same proportion as EM'' is greater than EM.

38. Nothing can be more calculated to excite our wonder and admiration than the distinctness of our perception of visible objects, compared with the magnitude of the picture on the retina, from which immediately we receive such perception.

39. If we look at the full moon on a clear night, we perceive with considerable distinctness by the naked eye the lineaments of light and shade which characterise its disk. Now let us consider only for a moment what are the dimensions of the picture of the moon formed on the retina, from which alone we derive this distinct perception.

The disk of the moon subtends a visual angle of half a degree, and consequently, according to what has been explained, the diameter of its picture on the retina will be $\frac{1}{230}$th part of an inch, and the entire superficial magnitude of the image from which we derive this distinct perception is only the $\frac{1}{52900}$th part of a square inch; yet within this minute space, we are able to distinguish a multiplicity of still more minute details. We perceive, for example, forms of light and shade, whose linear dimensions do not exceed one-tenth part of the apparent diameter of the moon, and which therefore occupy upon the retina a space whose diameter does not exceed the $\frac{1}{5000000}$th part of a square inch.

40. To take another example, the figure of a man 70 inches high, seen at a distance of 40 feet, produces an image upon the retina the height of which is about one-fourteenth part of an inch. The face of such an image is included in a circle whose diameter is about one-twelfth of the height, and therefore occupies on the retina a circle whose diameter is about the $\frac{1}{170}$th part of an inch; nevertheless, within this circle, the eyes, nose, and lineaments are distinctly seen. The diameter of the eye is about one-twelfth of that of the face, and therefore, though distinctly seen, does not occupy upon the retina a space exceeding the $\frac{1}{4000000}$th of a square inch.

If the retina be the canvas on which this exquisite miniature is delineated, how infinitely delicate must be its structure, to receive and transmit details so minute with such marvellous precision; and if, according to the opinion of some, the perception of these details be obtained by the retina *feeling* the image formed upon the choroid, how exquisitely sensitive must be its touch!

41.—3°. SUFFICIENCY OF ILLUMINATION.

It is not enough for distinct vision that a well-defined picture of the object shall be formed on the retina. This picture must be sufficiently illuminated to affect the sense, and at the same time not be so intensely illuminated as to overpower the organ.

Thus it is possible to conceive a picture on the retina so extremely faint as to be insufficient to produce sensation, or, on the other hand, so intensely brilliant as to dazzle the eye, to destroy the distinctness of sense, and to produce pain.

When we direct the eye to the sun, near the meridian, in an unclouded sky, we have no distinct perception of his disk, because the splendour is so great as to overpower the sense of vision, just as sounds are sometimes so intense as to be deafening.

That it is the intense splendour alone which prevents a distinct perception of the solar disk in this case is rendered manifest by the fact that if a portion of the solar rays be intercepted by a coloured glass, or by a thin cloud, a distinct image of the sun will be seen.

When we direct the eye to the firmament on a clear night, there are innumerable stars which transmit light to the eye, and which therefore must produce some image on the retina, but of which we are altogether insensible, owing to the faintness of the illumination. That the light, however, does enter the eye and arrive at the retina is proved by the fact that if a telescope be directed to the stars in question, so as to collect a greater quantity of their light upon the retina, they will become visible.

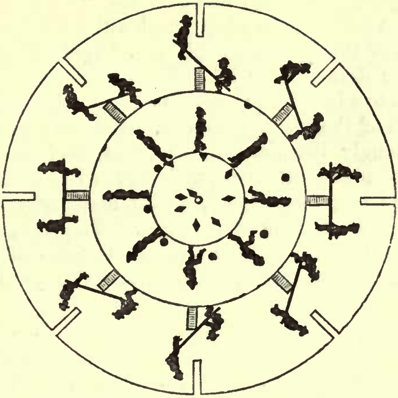


Fig. 8.—THE THAUMATROPE.

THE EYE.

CHAPTER II.

42. Power of accommodation of the eye.—43, 44. Apparent brightness of luminous objects. — 45-47. Intensity of brightness. — 48-57. The image must continue a sufficient time upon the retina to enable that membrane to produce a perception of it—Various illustrations of this. —58. Conditions which determine apparent motion.—59. How affected by distance.—60. Example.—61. When imperceptible.—62. Motion of the firmament.—63. Objects in rapid motion invisible. —64-66. Duration of the impression on the retina.—67. Optical toys. —68, 69. Coincidence of the optical and geometrical centres of the eye.—70. Ocular spectra and accidental colours.—71. Why visible objects do not appear inverted.—72. The seat of vision.—73-75. The optic nerve insensible to light.

42. The eye possesses a certain limited power of accommodating itself to various degrees of illumination. Circumstances which are familiar to every one render the exercise of this power evident.

If a person, after remaining a certain time in a dark room, pass suddenly into another room strongly illuminated, the eye suffers instantly a degree of inconvenience, and even pain, which causes the eyelids to close; and it is not until after the lapse of a certain time that they can be opened without inconvenience.

The cause of this is easily explained. While the observer remains in the darkened or less illuminated room, the pupil is dilated so as to admit into the eye as great a quantity of light as the structure of the organ allows of. When he passes suddenly into the strongly illuminated room, the flood of light arriving through the widely dilated pupil acts with such violence on the retina as to produce pain, which necessarily calls for the relief and protection of the organ. The iris, then, by an action peculiar to it, contracts the dimensions of the pupil so as to admit proportionally less light, and the eye is opened with impunity.

Effects the reverse of these are observed when a person passes from a strongly illuminated room into one comparatively dark, or into the open air at night. For a certain time he sees nothing, because the contraction of the pupil, which was adapted to the strong light to which it had previously been exposed, admits so little light to the retina that no sensation is produced. The pupil, however, after a while dilates, and, admitting more light, objects are perceived which were before invisible.

43. It is sometimes inferred, though erroneously, that the apparent splendour of the image of a visible object decreases as the square of the distance increases. This would be the case in the strictest sense, if, while the object were withdrawn from the eye to an increased distance, its image on the retina continued to have the same magnitude; for, in this case, the absolute brightness of each point composing such image would diminish as the square of the distance increases, and the area of the retina over which such points are diffused would remain the same; but it must be considered, that as the object retires from the eye the superficial magnitude of the image on the retina is diminished in the same proportion as the square of the distance of the object from the eye is increased. It therefore follows that while the points composing the image on the retina are diminished in the intensity of their illumination, they are collected into a smaller space, so that what each point of the image on the retina loses in splendour, the entire image gains by concentration.

44. If the sun were brought as close to the earth as the moon, its apparent diameter would be 400 times greater, and the area of its apparent disk 160000 times greater than at present, but the apparent brightness of its surface would not be in any degree increased. In the same manner, if the sun were removed to ten times its present distance, it would appear under a visual angle ten times less than at present, as in fact it would to an observer

on the planet Saturn, and its visible area would be a hundred times less than it is, but the splendour of its diminished area would be exactly the same as the present splendour of the sun's disk.

The sun seen from the planet Saturn has an apparent diameter ten times less than it has when seen from the earth.

The appearance from Saturn will then be the same as would be the appearance of a portion of the disk of the sun seen from the earth through a circular aperture in an opaque plate, which would exhibit a portion of the disk whose diameter is one-tenth of the whole.

45. When the light which radiates from a luminous object has a certain intensity, it will continue to affect the retina in a sensible manner, even when the object is removed to such a distance that the visual angle shall cease to have any perceivable magnitude. The fixed stars present innumerable examples of this effect. None of these objects, even the most brilliant of them, subtend any sensible angle to the eye. When viewed through the most perfect telescopes they appear merely as brilliant points. In this case, therefore, the eye is affected by the light alone, and not by the magnitude of the object seen.

46. Nevertheless the distance of such an object may be increased to such an extent that the light, intense as it is, will cease to produce a sensible effect upon the retina.

There are seven classes of the fixed stars, diminishing gradually in brightness,* which produce an effect on the retina such as to render them visible to a naked eye. This diminution of splendour is produced by their increased distance. The telescope brings into view innumerable other stars, whose intrinsic splendour is as great as the brightest among those which we see, but which do not transmit to the retina, without the aid of the telescope, enough of light to produce any sensible effect. It is demonstrable, however, that, even without the telescope, they do transmit a certain definite quantity of light to the retina; the quantity of light which they thus transmit, and which is insufficient to produce a sensible effect, having to the quantity obtained by the telescope a ratio depending upon the proportion of the magnitude of the object-glass of the telescope to the magnitude of the pupil.

47. The quantity and intensity of the light transmitted by an external object to the retina, which is sufficient to produce a perception of such object, depends also upon the light received at the

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* The term magnitude is used in astronomy, as applied to the fixed stars, to express their apparent brightness; no fixed star, however splendid, subtends any sensible angle.

same time by the retina from other objects present before the eye. The proof of this is, that the same objects which are visible at one time are not visible at another, though equally before the eye, and transmitting equal quantities of light of the same intensity to the retina. Thus, the stars are present in the heavens by day as well as by night, and transmit the same quantity of light to the retina, yet they are not visible in the presence of the sun, because the light proceeding from that luminary, directly and indirectly reflected and refracted by the air and innumerable other objects, is so much greater in quantity and intensity as to overpower the inferior and much less intense light of the stars. This case is altogether analogous to that of the ear, which when under the impression of loud and intense sounds, is incapable of perceiving sounds of less intensity, which nevertheless affect the organ in the same manner as they do when, in the absence of louder sounds, they are distinctly heard.

Even when an object is perceived, the intensity of the perception is relative, and determined by other perceptions produced at the same time. Thus, the moon seen at night is incomparably more splendid than the same moon seen by day or in the twilight, although in each case the moon transmits precisely the same quantity of light, of precisely the same intensity, to the eye; but in the one case the eye is overpowered by the superior splendour of the light of day, which dims the comparatively less intense light proceeding from the moon.

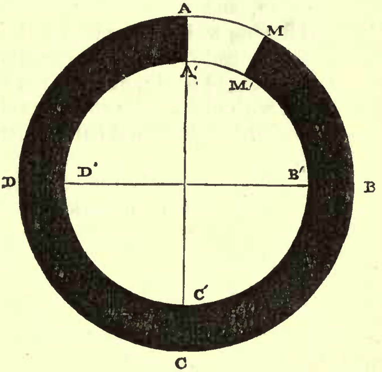
48.—4°. THE IMAGE MUST CONTINUE A SUFFICIENT TIME UPON THE RETINA TO ENABLE THAT MEMBRANE TO PRODUCE A PERCEPTION OF IT.

The velocity with which light is propagated through space is at the rate of about 200000 miles per second. Its transmission, therefore, from all objects at ordinary distances to the eye may be considered as instantaneous. The moment, therefore, any object is placed before the eye an image of it is formed on the retina, and this image continues there until the object is removed. Now it is easy to show experimentally that an object may be placed before the eye for a certain definite interval of time, and that a picture may be painted upon the retina during that interval without producing any perception or any consciousness of the presence of the object.

To illustrate this, let a circular disk A B C D, fig. 5, about twenty inches in diameter, be formed in card or tin, and let a circle A′ B′ C′ D′ be described upon it, about two inches less in radius than the disk, so as to leave between the circle and the disk a zone about two inches wide. Let the entire zone be blackened, except the space A M M′ A′, forming about the one-twentieth of it.

Let the disk thus prepared be attached to the back of a blackened screen, so as to be capable of revolving behind it, and let a hole one inch in diameter be made in the screen at any point, behind which the zone A B C D is placed. If the disk be now made to revolve behind the screen, the hole will appear as a circular white spot so long as the white space A M passes behind it, and will disappear, leaving the same black colour as the screen during the remainder of the revolution of the disk. The hole will therefore be seen as a white circular spot upon the black screen during one-twentieth of each revolution of the disk. If the disk be now put in motion at a slow rate, the white hole will be seen on the screen during one-twentieth of each revolution. If the velocity of rotation imparted to the disk be gradually increased, the white spot will ultimately *disappear*, and the screen appear of a uniform black colour, although it be certain that during the twentieth part of each revolution, whatever be the rate of rotation, a picture of the white spot is formed on the retina.

Fig. 5.



49. The length of time necessary in this case for the action of light upon the retina to produce sensation may be determined by ascertaining the most rapid motion of the disk which is capable of producing a distinct perception of the white spot. This interval will be found to vary with the degree of illumination. If the spot be strongly illuminated, a less interval will be sufficient to produce a perception of it; if it be more feebly illuminated, a longer interval will be required. The experiment may be made by varying the colour of the space A M of the zone, and it will be found that the interval necessary to produce sensation will vary with the colour as well as with the degree of illumination.

50. Numerous observations on the most familiar effects of vision, and various experiments expressly contrived for the purpose, show that the retina, when once impressed with the picture of an object placed before the eye, retains this impression, sometimes with its full intensity and sometimes more faintly, just as the ear retains for a time the sensation of a sound after the cause which has put the tympanum in vibration has ceased to act. The

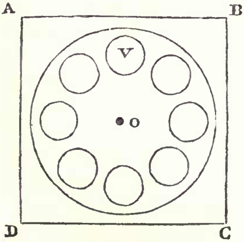
duration of this impression on the retina, after the removal of the visible object which produced it, varies according to the degree of illumination and the colour of the object. The more intense the illumination, and the brighter the colour, the longer will be the interval during which the retina will retain their effects.

51. To illustrate this experimentally, let a circular disk formed of blackened card or tin, of twelve or fourteen inches in diameter, be pierced with eight holes round its circumference, at equal distances, each hole being about half an inch in diameter, as represented in fig. 6.

Let this disk be attached upon a pivot or pin at its centre O to a board A B C D, which is blackened everywhere, except upon a circular spot at V, corresponding in magnitude to the holes made in the circular plate.

Let this spot be first supposed to be white. Let the circular disk be made to revolve upon the point O, so as to bring the circular holes successively before the white spot at V. The retina will thus be impressed at intervals with the image of this circular white spot. In the intervals between the transits of the holes over it, the entire board will appear black, and the retina will receive no impression. If the disk be made to revolve with a very slow motion, the eye will see the white spot at intervals, but if the velocity of rotation be gradually increased, it will be found that the eye will perceive the white spot permanently represented at V, as if the disk had been placed with one of its holes opposite to it without moving. It is evident, therefore, that in this case the impression produced upon the retina, when any hole is opposite the white spot, remains until the succeeding hole comes opposite to it, and thus a continued perception of the white spot is produced.

Fig. 6.



If the white spot be illuminated in various degrees, or if it be differently coloured, the velocity of the disk necessary to produce a continuous perception of it will differ. The brighter the colour and the stronger the illumination, the less will be the velocity of rotation of the disk which is necessary to produce a continuous perception of the spot.

These effects show that the stronger the illumination and the brighter the colour, the longer is the interval during which the impression is retained by the retina.

52. This continuance of the impression of external objects on the

retina, after the light from the object ceases to act, is also manifested by the fact, that the continual winking of the eyes for the purpose of lubricating the eye-ball by the eye-lid does not intercept our vision. If we look at any external objects, they never cease for a moment to be visible to us, notwithstanding the frequent intermissions which take place in the action of light upon the retina in consequence of its being thus intercepted by the eye-lid.

53. If a lighted stick be turned round in a circle in a dark room, the appearance to the eye will be a continuous circle of light; for in this case the impression produced upon the retina by the light, when the stick is at any point of the circle, is retained until the stick returns to that point.

54. In the same manner, a flash of lightning appears to the eye as a continuous line of light, because the light emitted at any point of the line remains upon the retina until the cause of the light passes over the succeeding points. In the same manner, any objects moving before the eye with such a velocity that the retina shall retain the impression produced at one point in the line of its motion until it passes through the other points, will appear as a continuous line of light or colour.

55. But to produce this effect, it is not enough that the body change its position so rapidly that the impression produced at one point of its path continues until its arrival at another point; it is necessary, also, that its motion should not be so rapid as to make it pass from any of the positions which it successively assumes before it has time to impress the eye with a perception of it; for it must be remembered, as has been already explained, that the perception of a visible object presented to the eye, though rapid, is not instantaneous.

The object must remain present before the organ of vision a certain definite time, and its position must continue upon the retina during such time, before any perception of it is obtained. Now, if the body move from its position before the lapse of this time, it necessarily follows that no perception of its presence, therefore, will be obtained. If, then, we suppose a body moving so rapidly before the eye that it remains in no position long enough to produce a perception of it, such object will not be seen.

56. Hence it is that the ball discharged from a cannon passing transversely to the line of vision is not seen; but if the eye be placed in the direction in which the ball moves, so that its angular motion round the eye as a centre will be slow notwithstanding its great velocity, it will be visible, because, however rapid its real motion through space, its angular motion with respect to the eye (and consequently of the image of its picture on the retina) will

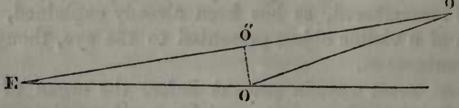
be sufficiently slow to give the necessary time for the production of a perception of it.

57. The time thus necessary to obtain the perception of a visible object varies with the degree of illumination, the colour, and the apparent magnitude of the object. The more intense the illumination the more vivid the colour, and the greater the apparent magnitude the less will be the time necessary to produce a perception of the object.

58. In applying this principle to the phenomena of vision, it must be carefully remembered that the question is affected, not by the real but by the apparent motion of the object, that is to say, not by the velocity with which the object really moves through space, but by the angle which the line drawn from the eye to the object describes per second. Now this angle is affected by two conditions, which it is important to attend to: 1°. the direction of the motion of the object compared with the line of vision; and 2°. by the velocity of the motion compared with the distance of the object. If the object were to move exactly in the direction of the line of vision, it would appear to the eye to be absolutely stationary, since the line drawn to it would have no angular motion; and if it were to move in a direction forming an oblique angle to the line of vision, its apparent motion might be indefinitely slow, however great its real velocity might be.

For example, let it be supposed that the eye being at E, fig. 7, an object O moves in the direction of O O′, so as to move from O to O′ in one second. Taking E as a centre, and E O as a radius, let a circular arc O O″ be described. The apparent motion of the object will then be same as if, instead of moving from O to O′ in one second, it moved from O to O″ in one second.

Fig. 7.



The more nearly, therefore, at right angles to the line of vision the direction of the motion is, the greater will be the apparent motion produced by any real motion of an object.

59. A motion which is visible at one distance may be invisible at another, inasmuch as the angular velocity will be increased as the distance is diminished.

Thus if an object at a distance of 57½ feet from the eye move at the rate of a foot per second, it will appear to move at the rate of one degree per second, inasmuch as a line one foot long at 57½ feet distance subtends an angle of one degree. Now if the eye be removed from such an object to a distance of 115 feet, the apparent motion will be half a degree, or thirty minutes per second; and if it be removed to thirty times that distance, the apparent motion will be thirty times slower. Or if, on the other hand, the eye be brought nearer to the object, the apparent motion will be accelerated in exactly the same proportion as the distance of the eye is diminished.

60. A cannon-ball moving at 1000 miles an hour transversely to the line of vision, and at a distance of 50 yards from the eye, will be invisible, since it will not remain a sufficient time in any one position to produce perception. The moon, however, moving with more than double the velocity of the cannon-ball, being at a distance of 240000 miles, has an apparent motion, so slow as to be imperceptible.

61. The angular motion of the line of vision may be so diminished as to become imperceptible; and the body thus moved will in this case appear stationary. It is found by experience that unless a body move in such a manner that the line of vision shall describe at least one degree in each minute of time, its motion will not be perceptible.

62. Thus it is that we are not conscious of the diurnal motion of the firmament. If we look at the moon and stars on a clear night, they appear to the eye to be quiescent; but if we observe them after the lapse of some hours, we find that their positions are changed, those which were near the horizon being nearer the meridian, and those which were in the meridian having descended towards the horizon. Since we are conscious that this change did not take place suddenly, we infer that the entire firmament must have been in continual motion round us, but that this motion is so slow as to be imperceptible.

Since the heavens appear to make a complete revolution in twenty-four hours, each object on the firmament must move at the rate of 15° an hour, or at the rate of one quarter of a degree a minute. But since no motion is perceptible to the eye which has a less apparent velocity than 1° per minute, this motion of the firmament is unperceived. If, however, the earth revolved on its axis in six hours instead of twenty-four hours, then the sun, moon, stars, and other celestial objects, would have a motion at the rate of 60° an hour, or 1° per minute. The sun would appear to move over a space equal to twice its own diameter each minute, and this motion would be distinctly perceived.

The fact that the motion of the hands of a clock is not perceived is explained in the same manner.

63. If an object which moves very rapidly be not sufficiently

illuminated, or be not of a sufficiently bright colour to impress the retina sensibly, it will then, instead of appearing as a continuous line of colour, cease to be visible altogether; for it does not remain in any one position long enough to produce a sensible effect upon the retina. It is for this reason that a ball projected from a cannon or a musket, though passing before the eye, cannot be seen. If two railway trains pass each other with a certain velocity, a person looking out of the window of one of them will be unable to see the other. If the velocity be very moderate, and the light of the day sufficiently strong, the appearance of the passing train will be that of a flash of colour formed by the mixture of the prevailing colours of the vehicles composing it.

An expedient has been contrived, depending on this principle, to show experimentally that the mixture of the seven prismatic colours, in their proper proportions, produces white light. The colours are laid upon a circular disk surrounding its edge, which they divide into parts proportional to the spaces they occupy in the spectrum. When the disk is made to revolve, each colour produces, like the lighted stick, the impression of a continuous ring, and consequently the eye is sensible of seven rings of the several colours superposed one upon the other, which thus produce the effect of their combination, and appear as white or a whitish grey colour.

64. The duration of the impression upon the retina, after the object producing it is removed, varies according to the vividness of the light proceeding from the object, being longer according as the light is more intense. It was found that the light proceeding from a piece of coal in combustion moved in a circle at a distance of 165 feet, produced the impression of a continuous circle of light when it revolved at the rate of seven times per second. The inference from this would be that in that particular case the impression upon the retina was continued during the seventh part of a second after the removal of the object.

It is from the cause here indicated that forked lightning presents the appearance of a continuous line of light.

65. The duration of the impression on the retina varies also with the colour of the light, that produced by a white object being most visible, and yellow and red being most in degree of durability; the least durable being those tints which belong to the most refrangible lights.

66. The duration of the impression also depends on the state of illumination of the surrounding space; thus the impression produced by a luminous object when in a dark room is more durable than that which would be produced by the same object seen in an illuminated room. This may be ascribed to the greater sensitiveness

of the retina when in a state of repose than when its entire surface is excited by surrounding lights. Thus it is found that while the varying duration of the impression of the illuminated object in a dark room was one-third of a second, its duration in a lighted room was only one-sixth of a second.

67. Innumerable optical toys and pyrotechnic apparatus owe their effect to this continuance of the impression upon the retina when the object has changed its position.

Amusing toys, called thaumatropes, phenakisticopes, phantaskopes, &c., are explained upon this principle. A moving object, which assumes a succession of different positions in performing any action, is represented in the successive divisions of the circumference of a circle, as in fig. 8, in the successive positions it assumes. These pictures, by causing the disk to revolve, are brought in rapid succession before an aperture, through which the eye is directed, so that the pictures representing the successive attitudes are brought one after another before the eye at intervals; the impression of one remaining until the impression of the next is produced. In this manner the eye never ceases to see the figure, but sees it in such a succession of attitudes as it would assume if it revolved. The effect is, that the figure actually appears to pirouette before the eye. The effects of catherine-wheels and rockets are explained in the same manner.

68. The direction in which any part of an object is seen is that of the line drawn from such point through the optical centre of the eye. This line being carried back to the retina determines the place on the retina where the image of such point is found. If the optical centre of the eye were not at the centre of the eye-ball, the direction of this line would be changed with every movement of the eye-ball in its socket; every such movement would cause the optical centre to revolve round the centre of the eye-ball, and consequently would cause the line drawn from the optical centre to the object to change its direction. The effect of this would be that every movement of the eye-ball would cause an apparent movement of all visible objects. Now, since there is no apparent motion of this kind, and since the apparent position of external objects remains the same, however the eye may be moved in its socket, it follows that its optical centre must be at the centre of the eye-ball.

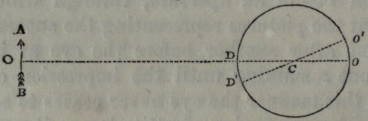
69. Since lines drawn from the various points of a visible object through the centre of the eye remain unchanged, however the eye-ball may move in its socket, and since the corresponding points of the image placed upon these lines must also remain unchanged, it follows that the position of the image formed on the eye remains fixed, even though the eye-ball revolve in the

socket. It appears, therefore, that when the eye-ball is moved in the socket, the picture of an external object remains fixed, while the retina moves under it, just as the picture thrown by a magic lantern on a screen would remain fixed, however the screen itself might be moved.

Thus, if we direct the axis of the eye to the centre O, fig. 9, of any object, such as A B, the image of the point O will be formed at *o* on the retina, where the optical axis D C meets it. The axis of the pencil of rays which proceed from the point O will pass through the centre of the cornea D, through the axis of the crystalline, and through the centre C of the eye-ball, and the image of O will be formed at *o*.

Now, if we suppose the eye to be turned a little to the left, so that the optical axis will be inclined to the line O C at the angle D′ C O, the image of the point O will still hold the same absolute position *o* as before; but the point of the retina on which it was previously formed will be removed to *o*′. The direction of the point O will be the same as before; but the point of the retina on which its image will be formed will be, not at *o*, at the extremity of the optic axis, but at *o*′, at a distance *o o*′ from it, which subtends at the centre C of the eye an angle equal to that through which the optical axis has been turned.

Fig. 9.

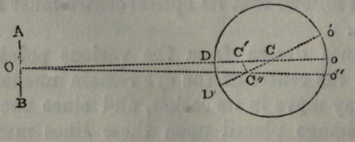


It is evident, therefore, that although the eye in this case be moved round its centre, the point O is still seen in the same direction as before.

But if the optical centre of the eye were different from the centre of the eye-ball, the direction in which the point O would be seen would be changed by a change of position of the eye.

To render this more clear, let C, fig. 10, be the centre of the eye-ball, and C′ the optical centre of the eye. Let the optical axis C D, as before, be first presented to the point O of the object.

Fig. 10.



The image of this point will, as before, be formed at *o*, the point where the optical axis D C meets the retina. Let us now suppose the axis of the eye to be turned aside through the angle D C D′, the optical centre will then be removed from C′ to C″, and the image of *o* will now be formed at the point *o*″, where the line O C″ meets the retina. The direction, therefore, in which O will now be seen, will be that of the line C″ O, whereas the direction in which it was before seen was that of the line C O. The point of the retina at which the image *o* was originally formed is removed to *o*′, while the image is removed to *o*″. Thus there is a displacement not only of the retina behind the image, but also an absolute displacement of the image, and an absolute change in the apparent direction of the object. Since no such change in the apparent direction is consequent upon the movement of the eye in its socket, it follows that the optical centre C′ of the eye must coincide with its geometrical centre C.

70. The continuance of the effect produced by the image of a visible object on the retina after such object has been removed from before the eye, combined with the effect of the image of another object placed before the eye during such continuance of the effect of that which was removed, produces a class of phenomena called *ocular spectra* and *accidental colours*.

The effect produced by a strongly illuminated image formed on the retina does not appear to be merely the continuance of the same perception after the image is removed, but also a certain diminution or deadening of the sensibility of the membrane to other impressions. If the organ were merely affected by the continuance of the perception of the object for a certain time after its removal, the effect of the immediate perception of another object on the retina would be the perception of the mixture of two colours. Thus, if the eye, after contemplating a bright yellow object, were suddenly directed to a similar object of a light red colour, the effect ought to be the perception of an orange colour; and this perception would continue until the effect of the yellow object on the retina would cease, after which the red object would alone be perceived.

Thus, for example, a disk of white paper being placed upon a black ground, and over it a red wafer which will exactly cover it being laid, if, closing one eye, and gazing intently with the other for a few seconds on the red wafer, the red wafer be suddenly removed so as to expose the white surface under it to the eye, the effect ought to be the combination of the perception of red which continues after the removal of the red wafer, with the perception of white which the uncovered surface produces; and we should consequently expect to see a diluted red disk, similar to that which would be produced by the mixture of red with white.

This, however, is not the case. If the experiment be performed as here described, the eye will, on the removal of the red wafer, perceive, not a reddish, but a greenish-blue disk.

In like manner, if the wafer, instead of being red, were of a bright greenish-blue, when removed the impression on the eye would be that of a reddish disk.

These and like phenomena are explained as follows:—

When the eye is directed with an intensity of gaze for some time at the red surface, that part of the retina upon which the image of the red wafer is produced becomes fatigued with the action of the red light, and loses to some extent its sensibility to that light, exactly as the ear is deafened for a moment by an overpowering sound. When the red wafer is removed, the white disk beneath it transmits to the eye the white light, which is composed of all the colours of the spectrum. But the eye, from the previous action of the red light, is comparatively insensible to those tints which form the red end of the spectrum, such as red and orange, but comparatively sensible to the blues and greens, which occupy the other end. It is therefore that the eye perceives the white disk as if it were a greenish-blue, and continues to perceive it until the retina recovers its sensibility for red light.

71. A difficulty has been presented in the explanation of the functions of the eye to which, as it appears to me, undue weight has been given. It has been already explained, that the images of external objects which are depicted on the retina are inverted; and it has accordingly been asked why visible objects do not appear upside down. The answer to this appears to be extremely simple. Inversion is a relative term, which it is impossible to explain or even to conceive without reference to something which is not inverted. If we say that any object is inverted, the phrase ceases to have meaning unless some other object or objects are implied which are erect. If all objects whatever hold the same relative position, none can be properly said to be inverted; as the world turns upon its axis once in twenty-four hours, it is certain that the position which all objects hold at any moment is inverted with respect to that which they held twelve hours before, and to that which they will hold twelve hours later; but the objects as they are contemplated are always erect. In fine, since all the images produced upon the retina hold with relation to each other the same position, none are inverted with respect to others; and as such images alone can be the objects of vision, no one object of vision can be inverted with respect to any other object of vision;

and consequently, all being seen in the same position, that position is called the erect position.

72. Physiologists are not agreed as to the manner in which the perception of a visible object is obtained from the image formed in the interior of the eye. It is certain, however, that this image is the cause of vision, or that the means whereby it is produced are also instrumental in producing the perception of sight. It may also be considered as established that the perception of a visible object is more or less distinct, according to the greater or less distinctness of the image. But it would be a great error to assume that this image on the retina is itself seen, for that would involve the supposition of a second eye, beyond the first, or within it, by which such image on the retina would be viewed. Now, no means of communicating between the image on the retina and the sensorium exist except the usual conduits of all sensation, the nerves.

It has been already explained that the optic nerve, after entering the eye at a point near the nose, spreads itself over the interior of the globe of the eye behind the vitreous humour, and that this retina or network is perfectly transparent, the coloured image being formed not properly upon it, but upon the black surface of the choroid coat behind it. Now, it has been maintained, that the functions of vision are performed by this nervous membrane in a manner analogous to that by which the sense of touch is affected by external objects. The membrane of the retina, it is supposed, touching the coloured image, and being in the highest degree sensitive to it, just as the hand is sensitive to an object which it touches, receives from the coloured image an action which, being continued to the brain, produces perception there in accordance with the form and colour of the image upon the choroid. According to this view of the functions of vision, the retina *feels*, as it were, the image on the choroid, and transmits to the sensorium the impression of its colour and figure in the same manner as the hand of a blind person would transmit to the sensorium the form of an object which it touches.

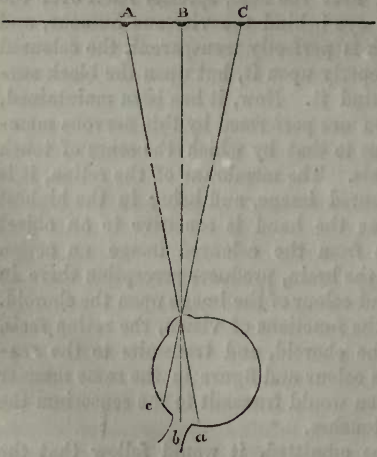
73. If this hypothesis be admitted, it would follow that the retina itself would be incapable of exciting the sense of sight by the mere action of light and colours upon it. This is verified by the fact that when the image produced within the eye is formed upon a point of the optic nerve which has not the choroid behind it, no perception is produced.

In order to prove this, let three wafers be applied in a horizontal line upon a vertical screen, each separated from the other by a distance of two feet. Let the screen be placed before the observer at a distance of about 15 feet, the wafers being on a level with the eye; and let the centre wafer be so placed that a line drawn from the right eye to it shall be perpendicular to the screen. Let the left eye be now closed, and let the right eye be directed to the extreme wafer on the left, but so that all three wafers may still be perceived. Let another person now slowly move the screen, so as to bring it nearer to the observer, maintaining, however, the middle wafer in the direction of the eye at C. It will be found that the screen being so moved to a distance of 10 feet from the eye, the middle wafer will appear to be suddenly extinguished, and the extreme wafers on the right and left will be seen.

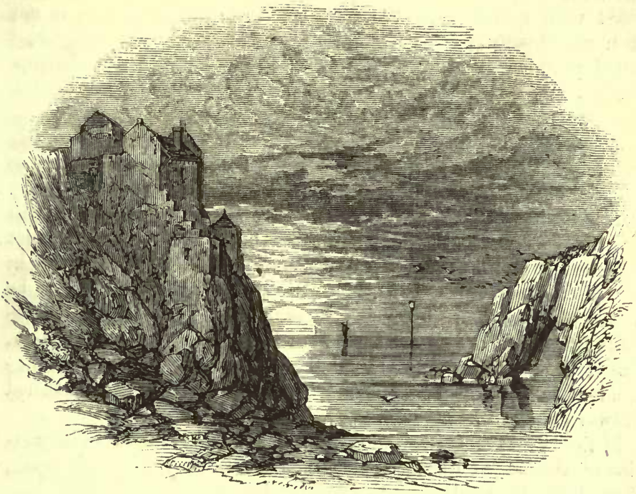
74. This remarkable phenomenon is explained by showing that in this particular position of the eye and the screen the image of the middle wafer falls upon the base of the optic nerve when the choroid coat is not under it.

This will be rendered more intelligible by reference to fig. 11, where B is the middle wafer, A the left-hand, and C the right-hand wafer. The image of A is formed at *a*, to the right of the optic nerve; and the image of C is formed at *c*, to the left of that nerve. In both these positions the choroid coat is behind the retina. But the image of B is formed at *b*, directly upon the point where the optic nerve issues from the eye-ball, and where the choroid does not extend behind it.

Fig. 11.



75. Sir David Brewster gives the following experiment as a further argument in support of this hypothesis. In the eye of the *Sepia loligo*, or cuttle-fish, an opaque membranous pigment is interposed between the retina and the vitreous humour, so that if the retina were essential to vision, the impression of the image on this black membrane must be conveyed to it by the vibration of this membrane in front of it. Sir David Brewster also mentions that in young persons the choroid coat, instead of being covered with a black pigment, reflects a brilliant crimson, like that of dogs and some other animals; and imagines that if the retina were affected by the rays which pass through it, this crimson light ought to excite a corresponding sensation, which is not the case.



THE EYE.

CHAPTER III.

76. Why objects are not seen double. — 77. Exceptional cases.— 78. The eye has no direct perception of distance or magnitude.— 79. How distances are estimated.—80. Appearance of the sun and moon when rising or setting.—81. How magnitudes are estimated. —82. Illusion produced in St. Peter's at Rome.—83. Magnitude inferred from distance. — 84. Perception of angular motion.—85. How real direction of motion may be inferred.—86. Examples of the sun and moon. — 87-90. Effect of the motion of the observer— Examples. —91. Angular distance defined. —92. The eye has no direct perception of form—How inferred.—93. Visible area defined. —94. Figure inferred from lights and shadows.—95. Power of distinguishing colours.—96, 97. Absence of this power in particular cases.

76. The question why, having two eyes on which independent impressions are made by external objects, and on the retina of each of which an independent picture of a visible object is formed, we do not see distinct objects corresponding to each individual external object which impresses the organ, is often asked.

The first reflection which arises on the proposition of this question, is why the same question has not been similarly proposed with reference to the sense of hearing. Why has it not been asked why we do not hear double? why each individual sound produced by a bell or a string is not heard as two distinct sounds, since it must impress independently and separately the two organs of hearing?

It cannot be denied, that, whatever reason there be for demanding a solution of the question, why we do not see double? is equally applicable to the solution of the analogous question, why we do not hear double? Like many disputed questions, this will be stripped of much of its difficulty and obscurity by a strict attention to the meaning of the terms used in the question, and in the discussion consequent upon it. If by seeing double it be meant that the two eyes receive separate and independent impressions from each external object, then it is true that we see double. But if it be meant that the mind receives two distinct and independent impressions of the same external object, then a qualified answer only can be given.

If the two eyes convey to the mind precisely the same impression of the same external object, differing in no respect whatever, then they will produce in the mind precisely the same perception of the object; and as it is impossible to imagine two perceptions to exist in the mind of the same external object which are precisely the same in all respects, it would involve a contradiction in terms to suppose that, in such case, we perceive the object double.

If to perceive the object double mean anything, it means that the mind has two perceptions of the same object, distinct and different from each other in some respect. Now, if this distinctness or difference exist in the mind, a corresponding distinctness and difference must exist in the impression produced of the external object on the organs. It will presently appear, that cases do occur in which the organs are, in fact, differently impressed by the same external object; and it will also appear, that in such cases precisely we *do see double*, meaning by these terms, that we have two perceptions of the same object, as distinct from each other as are our perceptions of two different objects.

To render this point more clear, let us consider in what respects it is possible for the impressions made upon the two eyes by the same object to differ from each other.

A visible object impresses the eye with a sense of a certain apparent form, of a certain apparent magnitude, of certain colours, of a certain intensity of illumination, and of a certain visible direction. Now, if the impression produced by the same object upon the two eyes agree in all these respects, it is impossible to imagine that the mind can receive two distinct perceptions of the object, for it is not possible that the two perceptions could differ from each other in any respect, except in some of those just mentioned. Let us suppose the two eyes to look at the moon, and that such object impresses them with an image of precisely the same apparent form and magnitude, of precisely the same colours and lineaments, of precisely the same intensity of illumination, and in precisely the same direction. Now, the impressions conveyed to the mind by each of the eyes corresponding in all these respects, the object must be perceived in virtue of both impressions precisely in the same manner, that is to say, it must be seen in precisely the same direction, of precisely the same magnitude, of precisely the same form, with precisely the same lineaments of light and shade, and with precisely the same brightness or intensity of illumination. It is therefore, in such a case, clearly impossible to have a double perception of the object.

It will be observed, that the same reasoning exactly will be applicable to the sense of hearing. If the same string or the same pipe affect the tympanum of each ear in precisely the same manner, so as to produce a perception of a sound of the same pitch, the same loudness, and the same quality, it is impossible to conceive that two different perceptions can be produced by the two ears, for there is no respect in which it is possible for two such perceptions to differ, inasmuch as by the very supposition they agree in all the qualities which belong to sound.

But, if we could conceive by any organic derangement that the same musical string would produce in one ear the note *ut*, and produce in the other ear the note *sol*, then the same effect would be produced as if these two sounds had been simultaneously heard by the two ears properly organised, and we should have a sense of harmony of the *fifth*.

In like manner, if the two eyes, by any defect of organisation, produced different pictures on the retina, we should then have two perceptions of the same object having a corresponding difference.

It has been already shown, that the apparent visual magnitude of an object, and also that its apparent brilliancy, depend on its distance from the eye.

Now, assuming, as we shall do, unless the contrary be expressed, that the two eyes are similarly constituted, it will follow, that an object whose distance from the two eyes is equal will be seen under the same visual angle, and will therefore have the same apparent magnitude; it will also have the same colour and intensity of illumination, and, in fine, if the distance between the eyes bear an insignificant proportion to the distance of the object from them, the lines drawn from the centre of the eyes to any point on the object will be practically parallel; and since these lines, as has been already explained, determine the direction in which the object is seen, such object will then be seen in the same direction. Now, since the apparent form, the apparent magnitude, the apparent colour, the apparent intensity of illumination, and the apparent direction are the same for both eyes, it is clear that the same impression must be produced upon the senses, and the same perceptions conveyed to the mind; consequently it follows, demonstratively, that all objects which are placed at a distance compared with which the distance between the eyes is insignificant, will convey a single perception to the mind, and will consequently not be seen double.

77. But we have now to consider a different case, which will present peculiar conditions, and consequences of peculiar interest.

Let us suppose an object placed so near the eyes that its distance shall not bear a considerable proportion to the length of the line which separates the centres of the eyes. In this case, the images produced on the retina of the two eyes may differ in magnitude, and intensity of illumination, and even in form, and, in fine, it is clear that the apparent direction of any point on the object as seen by the two eyes will be sensibly different.

In this case, therefore, the two eyes convey to the mind a different impression of the same object; and we may therefore expect that we should see it double, and in fact we do so.

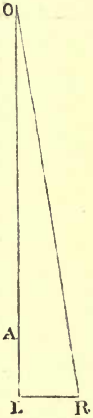
But the observation of this particular phenomenon requires much attention, inasmuch as the perception of which we are conscious is affected not merely by the impression made upon the organ of sense, but by the degree of attention which the mind gives to it. Thus, if the two eyes be differently impressed either by the same or by different objects placed before them, the mind may give its attention so exclusively to either impression, as to lose all consciousness of the other.

Thus, if two stars be at the same time in the field of view of a telescope, as frequently happens, and be viewed together by the eye, we shall be conscious of a perception of both, so long as the attention is not exclusively directed to either; but if we gaze intently on one of them so as to observe its colour, or any other peculiarity attending it, we shall cease to be conscious of the presence of the other. The application of this observation to the question before us will be presently apparent.

Let R L, fig. 12, be the line separating the centres of the two eyes, R representing the centre of the right, and L that of the left eye.

Let O be an object, such as the flame of a candle or lamp, seen at the distance of about 40 feet, so that the lines of direction L O and R O converging upon it from the centres of the eyes may be regarded as practically parallel, the distance being about 200 times greater than the distance L R between the eyes. The object O will therefore be seen in the same direction by both eyes, and being at a distance from the two eyes practically equal, will have the same apparent magnitude, form, colour, and intensity of illumination, and, consequently, will be seen single.

Fig. 12.



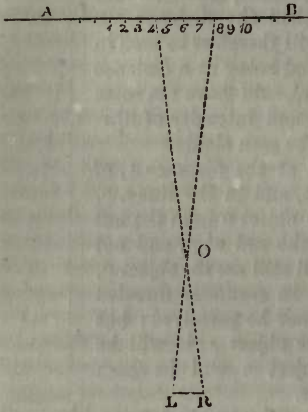
Let a small white rod be held at the distance A, of about 8 inches from the left eye L, and in the line L O, so as to intercept the view of the object O from the left eye. The left eye will then see the rod at A, and not the object O; but the right eye will still see the object O, as before. Now, if the attention be earnestly directed to the object O, the object A will not be perceived; but if the attention be directed to the object A, it will be perceived distinctly, but the object O will be seen through it as if it were transparent.

Now, since the object O cannot be seen by the left eye under the circumstances here supposed, the perception we have of it must be derived from the right eye; nevertheless it is seen in the line L A O, immediately beyond the intercepting wand, and in the same direction, and in the same manner precisely as it would be seen by the left eye L if the intercepting wand were removed. It follows, therefore, that the perception we obtain of the object O by the right eye is precisely the same as that which we should obtain by the left eye if the right were closed, and the intercepting wand A removed. This may therefore be taken as an experimental proof of what, indeed, may seem sufficiently evident, *à priori,* that an object, such as O, placed at a distance so great that lines drawn to it from the centre of the eyes would be practically parallel, produces precisely the same perception through the vision of both eyes.

But when the distance of an object from the eye is so small that the line which separates the eyes bears a considerable proportion to it, the directions in which such an object is seen by the two eyes are different, and it is easy to show that in this case such an object would be seen double.

Let L, and R (fig. 13), as before, be the centres of the two eyes, and let A B be a white screen placed vertically at a distance of 12 or 14 feet, having upon it a horizontal line on a level with the eye, upon which is marked a divided scale 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Let a black wand be held vertically at O, opposite the middle of the line L R. This wand will be seen by the left eye in the direction of the division 8, and by the right eye in the direction of the division 4, on the screen, and two images o the wand will accordingly be perceived; but, according as the attention is directed to the one or to the other, a consciousness of them will be produced. Thus, by an act of the will we may contemplate only the objects as seen with the left eye, in which case the wand will be seen projected on the screen perpendicular to the line A B, at the 8th division; and by a like act of the will, the attention being directed to the impression produced by the right eye, the wand will be seen projected on the screen at the 4th division of the scale. If the attention be withdrawn from either of these and the wand be viewed indifferently, we shall be conscious of the two images, but not with the same distinctness as that with which we should perceive two wands placed at the 4th and 8th divisions of the scale. It will follow from this, that when we look with both eyes at any object, such as the printed page of a book, at the distance of 8 or 10 inches from the eyes, we have two images of the different parts of the page placed before the eyes, which are seen in different directions, and ought therefore to produce double vision; but this is prevented by habitually directing our attention to one of the two, and neglecting the other.

Fig 13.



That the perception of an object will be double if the directions in which it is seen by the two eyes are different, may also be demonstrated in the following manner:—

It has been already shown that the optical centres of the eyes cannot change their position by the mere action of the muscles which move the eye-balls in their sockets, and that the direction in which any distant object is seen by both eyes is the same, and hence it is perceived single; but if a slight pressure be applied to the eye with the finger, the optical centre of the eye may be moved from its position, so that the direction of the same object seen by it and the other eye will not be the same. A distant object will in this case be seen double, being perceived in one direction by the eye which retains its natural position, and in another by that whose position is deranged by pressure.

78. It has been already explained that two similar objects whose distances from the eye are to each other in the same proportion as their linear dimensions will have the same apparent magnitude.

In like manner, if an object, such as, for example, a balloon, moves from the eye in a direct line, we have no distinct consciousness of its motion, for the line of direction in which it is seen is still the same. It is true that we may infer its motion through the air by the increase or diminution of its apparent magnitude; for, if we have reason to know that its real magnitude remains unchanged, we ascribe almost intuitively the change of its apparent magnitude to the change of its distance; and we consequently *infer* that it is in motion either towards or from us, according as we perceive its apparent magnitude to be increased or diminished. This information, however, as to the motion of a body in a direct line to or from the centre of the eye, is not a perception obtained directly from vision, but an inference of the reason deduced from certain phenomena. It may, therefore, be stated generally, that the eye affords no perception of direct distance, and consequently none of direct motion, the term direct being understood here to express a motion in a straight line to or from the optical centre of the eye.

79. The distance of a visible object is often estimated by comparing it with the apparent magnitude and apparent distance of known objects which intervene between it and the eye.

Thus, the steeple of a church whose real height is unknown cannot by mere vision be estimated either as to distance or magnitude, since the apparent height would be the same, provided its magnitude were greater or less in proportion to its supposed distance. But, if between the steeple and the eye there intervene buildings, trees, or other objects, whose average magnitudes may be estimated, a proximate estimate of the magnitude and distance of the steeple may be obtained.

For example, if the height of the most distant building between the eye and the steeple be known, the distance of that building may be estimated by its apparent magnitude, and the distance of the steeple will be inferred to be greater than this.

80. A remarkably deceptive impression, depending on this principle, is deserving of mention here. When the disc of the sun or moon at rising or setting nearly touches the horizon, it appears of enormous magnitude compared with its apparent size when high in the firmament. Now, if the visual angle which it subtends be actually measured in this case, it will be found to be of the same magnitude. How, then, it may be asked, does it happen that the apparent magnitude of the sun at setting and at

noon are by measure the same, when they are by estimation, and by the irresistible evidence of sense, so extremely different? This is explained, not by an error of the sense, for there is none, but by an erroneous application of those means of judging or estimating distance which in ordinary cases supply true and just conclusions.

When the disc of the sun is near the horizon, a number of intervening objects of known magnitude and known relative distances supply the means of spacing and measuring a part at least of the distance between the eye and the sun; but when the sun is in the meridian, no such objects intervene. The mind, therefore, assigns a greater magnitude to the distance, a part of which it has the means of measuring, than to the distance no part of which it can measure; and accordingly an impression is produced, that the sun at setting is at a much greater real distance than the sun in the meridian; and since its apparent magnitude in both cases is the same, its real magnitude must be just so much greater as its estimated distance is greater. The judgment, therefore, and not the eye, assigns this erroneous magnitude to the disc of the sun.

It is true that we are not conscious of this mental operation. But this unconsciousness is explained by the effect of habit, which causes innumerable other operations of the reason to pass unobserved.

81. As the eye forms no immediate perception of distance, neither does it of form or of magnitude, since, as has been already proved, objects of very different real magnitudes have the same apparent magnitude to the eye, of which a striking example is afforded in the case of the sun and moon. Nevertheless, although the eye supplies no immediate perception of the real magnitude of objects, habit and experience enable us to form estimates more or less exact of these magnitudes by the comparison of different effects produced by sight and touch.

Thus, for example, if two objects be seen at the same distance from the eye, the real magnitude of one of which is known, that of the other can be immediately inferred, since, in this case, the apparent magnitudes will be proportional to the real magnitudes. Thus, for example, if we see the figure of a man standing beside a tree, we form an estimate of the height of the latter, that of the former being known or assumed. Ascribing to the individual seen near the tree the average height of the human figure, and comparing the apparent height of the tree with his apparent height, we form an estimate of the height of the tree.

82. It is by this kind of inference that buildings constructed upon a scale greatly exceeding common dimensions are estimated, and rendered apparent in pictorial representations of them.

On entering, for example, the aisle of St. Peter's at Rome, or St. Paul's at London, we are not immediately conscious of the vastness of the scale of these structures; but if we happen to see at a distant part of the building a human figure, we immediately become conscious of the scale of the structure, for the known dimensions of this figure supply a modulus which the mind instantly applies to measure the dimensions of the whole. For this reason artists, when they represent these structures, never fail to introduce human figures in or near them.

83. It has been explained that the apparent magnitude of objects depends conjointly on their real magnitude and their distance. Although, therefore, the eye does not afford any direct perception either of real magnitude or distance, we are by habit enabled to infer one of these from the other.

Thus, if we happen to know the real magnitude of a visible object, we form an estimate of its distance from its apparent magnitude; and, on the other hand, if we happen to know or can ascertain the distance of an object, we immediately form some estimate of its real magnitude.

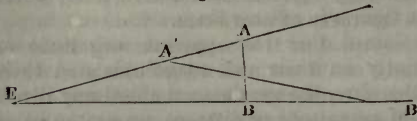
Thus, for example, the height of a human figure being known, if we observe its apparent visual magnitude to be extremely small, we know that it must be at a distance proportionally great. If we know that at 20 feet the figure of a man will have a certain apparent height, and that we find that his figure seen at a certain distance appears to have only one-fifth of this height, we infer that his distance must be about 100 feet.

In like manner, the real magnitude may be inferred from the apparent magnitude, provided the distance be known or can be ascertained. Thus, for example, in entering Switzerland by its northern frontier, we see in the distance, bounding the horizon, the line of the snowy Alps, and the first impression is that of disappointment, their apparent scale being greatly less than we expected; but when we are informed that their distance is sixty or eighty miles, our estimate is instantly corrected, and we become conscious that the real height of mountains which, seen at so great a distance, is what we observe it, must be proportionately vast.

84. When an object moves in any direction which is not in a straight line drawn to or from the centre of the eye, the direction in which it is seen continually changes, and the eye in this case supplies an immediate perception of its motion; but this perception can be easily shown to be one not entirely corresponding to the actual motion of the object, but merely to the continual change of direction which this motion produces in the line drawn from the object to the eye.

Thus, for example, if the eye be at E (fig. 14), any object which moves from A to B will cause the line of direction in which it is seen to revolve through the angle A E B, just as though the body which moves were to describe a circular arc, of which E is the centre and E A the radius. But if, instead of moving from A to B, the body were to move from A′ to B′, the impression which its motion would produce upon the sight would be exactly the same. It would still appear to be moving from the direction E A′ A to the direction E B B′.

Fig. 14.



In fine, the eye affording no perception of direct distance, supplies no evidence of the extent to which the body may change its distance from the eye during its motion, and the apparent motion will be the same as if the body in motion described a circle of which the eye is the centre.

Hence it is that the only motion of which the eye forms any immediate apprehension is angular motion, that is, a motion which is measured by the angle which a line describes, one extremity of which is at the centre of the eye, and the other at the moving object.

85. Though the real direction in which a distant object moves cannot be obtained by the direct perception of vision, some estimate of it may be formed by comparing the apparent angular motion of the object with its apparent magnitude.

Thus, for example, if we observe that the apparent magnitude of an object remains constantly the same while it has a certain apparent angular motion, we infer that its distance must necessarily remain the same, and consequently that it revolves in a circle, in the centre of which the observer is placed; or if we find that it has an angular motion, in virtue of which it changes its direction successively around us, so as to make a complete circuit of 360°, and that in making this circuit its apparent magnitude first diminishes to a certain limit, and then augments until it attains a certain major limit from which it again diminishes, we infer that such a body revolves round us at a varying distance, its distance being greatest when the apparent magnitude is least, and least when its apparent magnitude is greatest. An exact observation of the variation of the apparent magnitude would in such a case supply a corresponding estimate of the variation of the real distance, and would thus form the means of ascertaining the path in which the body moves.

86. An example of this is presented in the cases of the sun and

moon, whose apparent magnitudes are subject, during their revolution round the earth, to a slight variation, being a minimum at one point and a maximum at the extreme opposite point, the variation being such as to show that their motions are made in an ellipse in the focus of which the earth is placed.

87. As the eye perceives the motion of an object only by the change in the direction of the line joining the object with the eye, and as this change of direction may be produced as well by the motion of the observer as by that of the object, we find accordingly that apparent motions are produced sometimes in this manner. Thus, if a person be placed in the cabin of a boat which is moved upon a river or canal with a motion of which the observer is not conscious, the banks and all objects upon them appear to him to move in a contrary direction. In this case the line drawn from the object to the eye is not moved at the end connected with the object, which it would be if the object itself were in motion, but at the end connected with the eye. The change of its direction, however, is the same as if the end connected with the object had a motion in a contrary direction, the end connected with the eye being at rest; consequently the apparent motion of the objects seen which are really at rest, is in a direction contrary to the real motion of the observer.

88. In some cases the apparent motion of an object is produced by a combination of a real motion in the object and a real motion in the observer. Thus, if a person transported in a railway carriage meet a train coming in the opposite direction, both extremes of the line joining his eye with the train which passes him are in motion in contrary directions; that extremity which is at his eye is moved by the motion of the train which carries him, and the other extremity is moved by the motion of the train which passes him. The change of direction of the line is accordingly produced by the sum of these motions; and as this change of direction is imputed by the sense to the train which passes, this train appears to move with the sum of the velocities of the two trains. Thus, if one train be moved at twenty miles an hour, while the other is moved at twenty-five miles an hour, the apparent motion of the passing train will be the same as would be the motion of a train moved at forty-five miles an hour passing a train at rest.

89. If the line joining a visible object with the eye be moved at both its extremities in the same direction, which would be the case if the observer and the object were carried in parallel lines, then the change of direction which the line of motion would undergo would arise from the difference of the velocities of the observer and of the object seen.

If the observer in this case moved slower than the object, the extremity of the line of motion connected with the object would be carried forward faster than the extremity connected with the observer, and the object would appear to move in the direction of the observer's motion, with a velocity equal to the difference; but if, on the contrary, the velocity of the observer were greater than that of the object, the extremity of the line connected with the observer would be carried forward faster than that connected with the object, and the change of direction would be the same as if the object were moved in a contrary direction with the difference of the velocities.

It is easy to perceive that a vast variety of complicated relations which may exist between the directions and motions of the observer and of the object observed, will give rise to very complicated phenomena of apparent motion. Thus, relations may be imagined between the motion of the observer and that of the object perceived by which, though both are in motion, the object will appear stationary; the motion of the one affecting the line of direction in an equal and contrary manner to that with which it is affected by the other; and, in the same manner, either motion may prevail over the other more or less, so as to give the line of direction a motion in accordance with or contrary to the real motion of the object.

90. All these complicated phenomena of vision are presented in the problems which arise on the deduction of the real motion of the bodies composing the solar system from their apparent motions. The observer placed in the middle of this system is transported upon the earth in virtue of its annual motion round the sun with a prodigious velocity, the direction of his motion changing from day to day according to the curvature of the orbit. The bodies which he observes are also affected with various motions at various distances around the sun, the combination of which with the motion of the earth gives rise to complicated phenomena, the analysis of which is made upon the principles here explained.

91. It is usual to express the relative position in which objects are seen by the relative direction of lines drawn to them from the eye; and the angle contained by any two such lines is called the angular or visual distance between the objects. Thus, the angular distance between the objects A and B, fig. 14, is expressed by the magnitude of the angle A E B. If this angle be 30°, the objects are said to be 30° asunder. It is evident from this that all objects which lie in the direction of the same lines will be at the same angular distance asunder, however different their real distance from each other may be. Thus, the angular distance between A and B, fig. 14, is the same as the angular distance between A′ and B′.

92. Sight does not afford any immediate perception either of the volume or shape of an object. The information which we derive from the sense, of the bulk or figure of distant objects, is obtained by the comparison of different impressions made upon the sense of sight by the same object at different times and in different positions. A body of the spherical form seen at a distance appears to the eye as a flat circular disk, and would never be known to have any other form, unless the impression made upon the eye were combined with other knowledge, derived from other impressions through sight or touch, or both these senses, and thus supplied the understanding with data from which the real figure of the object could be inferred. The sun appears to the eye as a flat, circular disk; but, by comparing observations made upon it at different times, it is ascertained that it revolves round one of its diameters in a certain time, presenting itself under aspects infinitely varying to the observer; and this fact, combined with its invariable appearance as a circular disk, proves it to be a sphere; for no body except a sphere, viewed in every direction, would appear circular.

Although we do not obtain from the sense of sight a perception of the shape of a body, we may obtain a perception of the shape of one of its sections. Thus, if a section of the body be made by a plane passing through it at right angles to the line of vision, the sight supplies a distinct perception of the shape of such section. Thus, if an egg were presented to the eye with its length in the direction of the line of vision, it would appear circular, because a section of it made by a plane at right angles to its length is a circle; but if it were presented to the eye with its length at right angles to the line of vision, it would appear oval, that being the shape of a section made by a plane passing through its length.

If a body, therefore, presents itself successively to the eye in several different positions, we obtain a knowledge by the sense of sight of so many different sections of it, and the combination of these sections may in many cases supply the reason with data by which the exact figure of the body may be known.

93. As the term "apparent magnitude" is used to express the visual angle under which an object is seen, we shall adopt the term *visible area* to express the apparent magnitude of the section of a visible object made by a plane at right angles to the line of vision, that is to say, to the line drawn from the eye to the centre of the object.

94. Besides receiving through the sight a perception of the figure of the section of the object which forms its visible area, we also obtain a perception of the lights and shades and the various tints of colour which mark and characterise such area. By

comparing the perception derived from the sense of touch with those lights and shades, we are enabled by experience and long habit to judge of the figure of the object from these lights and shades and tints of colour. It is true that we are not conscious of this act of the understanding in inferring shape from colour and from light and shade; but the act is nevertheless performed by the mind. The first experience of inference is the comparison of the impressions of sight with the impressions of touch; and one of the earliest acts of the mind is the inference of the one from the other. It is the character of all mental acts, that their frequent performance produces an unconsciousness of them; and hence it is that when we look at a cube or a sphere of a uniform colour, although the impression upon the sense of sight is that of a flat plane variously shaded, and having a certain outline, the mind instantly substitutes the thing signified for the sign, the cause for the effect; and the conclusion of the judgment, that the object before us is a sphere or a cube of uniform colour, and not as it appears, a flat plane variously shaded, is so instantaneous, that the act of the mind passes unobserved.

The whole art of the painter consists in an intimate practical knowledge of the relation between these two effects of perception of sight and touch. The more accurately he is able to delineate upon a flat surface those varieties of light and shade which visible objects immediately produce upon the sense, the more exact will be his delineation, and the greater the *vraisemblance* of his picture.

What is called relief in painting is nothing more than the exact representation on a flat surface of the varieties of light and shade produced by a body of determinate figure upon the eye; and it is accordingly found that the flat surface variously shaded produced by the art of the painter has upon the eye exactly the same effect as the object itself, which is in reality so different from the coloured canvas which represents it.

95. The immediate impressions received from the sense of sight are those of light and colour. The impressions of distance, magnitude, form, and motion are the mixed results of the sense of sight and the experience of touch. Even the power of distinguishing colours is not obtained immediately by vision without some cultivation of this sense. The unpractised eye of the new-born infant obtains a general perception of light; and it is certain that the power of distinguishing colours is only found after the organ has been more or less exercised by the varied impressions produced by different lights upon it. It would not be easy to obtain a summary demonstration of this proposition from the experience of infancy, but sufficient evidence to establish it is supplied by

the cases in which sight has been suddenly restored to adults blind from their birth. In these cases, the first impression produced by vision is that the objects seen are in immediate contact with the eye. It is not until the hand is stretched forth to ascertain the absence of the objects seen from the space before the eye that this optical fallacy is dissipated.

The eye which has recently gained the power of vision at first cannot distinguish one colour from another, and it is not until time has been given for experience, that either colour or outline is perceived.

96. Besides that imperfection incident to the organs of sight arising from the excess or deficiency of their refractive powers, there is another class which appear to depend upon the quality of the humours through which the light proceeding from visible objects passes before attaining the retina. It is evident that if these humours be not absolutely transparent and colourless, the image on the retina, though it may correspond in form and outline with the object, will not correspond in colour ; for if the humours be not colourless, some constituents of the light proceeding from the object will be intercepted before reaching the retina, and the picture on the retina will accordingly be deprived of the colours thus intercepted. If, for example, the humours of the eye were so constituted as to intercept all the red and orange rays of white light, white paper, or any other white object, such as the sun, for example, would appear of a bluish-green colour; and if, on the other hand, the humours were so constituted as to intercept the blues and violets of white light, all white objects would appear to have a reddish hue. Such defects in the humours of the eye are fortunately rare, but not unprecedented.

97. Sir David Brewster, who has curiously examined and collected together cases of this kind, gives the following examples of these defects :—

A singular affection of the retina in reference to colour is shown in the inability of some eyes to distinguish certain colours of the spectrum. The persons who experience this defect have their eyes generally in a sound state, and are capable of performing all the most delicate functions of vision. Mr. Harris, a shoemaker at Allonby, was unable from his infancy to distinguish the cherries of a cherry-tree from its leaves, in so far as colour was concerned. Two of his brothers were equally defective in this respect, and always mistook orange for grass-green, and light green for yellow. Harris himself could only distinguish black and white. Mr. Scott, who describes his own case in the Philosophical Transactions, mistook pink for a pale blue, and a full red for a full green.

All kinds of yellows and blues, except sky-blue, he could discern with great nicety. His father, his maternal uncle, one of his sisters and her two sons, had all the same defect.

A tailor at Plymouth, whose case is described by Mr. Harvey, regarded the solar spectrum as consisting only of yellow and light blue; and he could distinguish with certainty only yellow, white, and green. He regarded indigo and Prussian blue as black.

Mr. R. Tucker described the colours of the spectrum as follows :—

Red mistaken for	brown.
Orange ,,	green.
Yellow sometimes	orange.
Green ,,	orange.
Blue ,,	pink.
Indigo ,,	purple.
Violet ,,	purple.

A gentleman in the prime of life, whose case I had occasion to examine, saw only two colours in the spectrum, viz. yellow and blue. When the middle of the red space was absorbed by a blue glass, he saw the black space with what he called the yellow on each side of it. This defect in the perception of colour was experienced by the late Mr. Dugald Stewart, who could not perceive any difference in the colour of the scarlet fruit of the Siberian crab, and that of its leaves. Dr. Dalton was unable to distinguish blue from pink by daylight; and in the solar spectrum the red was scarcely visible, the rest of it appearing to consist of two colours. Mr. Troughton had the same defect, and was capable of fully appreciating only blue and yellow colours; and when he named colours, the names of blue and yellow corresponded to the more and less refrangible rays; all those which belong to the former exciting the sensation of blueness, and those which belong to the latter the sensation of yellowness.

In almost all these cases, the different prismatic colours had the power of exciting the sensation of light, and giving a distinct vision of objects, excepting in the case of Dr. Dalton, who was said to be scarcely able to see the red extremity of the spectrum.

Dr. Dalton endeavoured to explain this peculiarity of vision by supposing that in his own case the vitreous humour was blue, and therefore absorbed a great portion of the red and other least refrangible rays; but this opinion is, we think, not well founded. Sir J. Herschell attributes this state of vision to a defect in the sensorium, by which it is rendered incapable of appreciating exactly those differences between rays on which their colour depends.

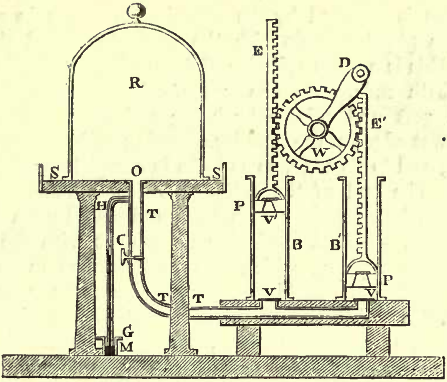


Fig. 6.—AIR-PUMP.

THE ATMOSPHERE.

1. Experimental proofs of the weight of the atmosphere.—2. The bladder glass.—3. Pressure equal in all directions.—4. Pressure of air in a room explained.—5. Magdeburg hemispheres.—6. Suction with tube.—7. Pascal's experiment at Rouen.—8. Horror of a vacuum.—9. Galileo and the pump-makers.—10. Torricelli's celebrated experiment.—11. Pascal's experiment on the Puy-de-dôme.—12. Actual pressure of atmosphere ascertained.—13. Height of an atmosphere of uniform density.—14. Vastly greater height of an elastic atmosphere.—15. Air less and less dense in ascending.—16. Effects of atmospheric pressure.—17. Boy's plaything of a sucker.—18. Flies walking on ceiling.—19. Respiration.—20. Action of bellows.—21. Ventpeg—lid of tea-pot.—22. Pneumatic ink-bottle.—23. Syringes.—24. Exhausting syringe.—25. Rate of rarefaction.—26. Absolute vacuum cannot be obtained.—27. But may be indefinitely approached.—28. Air-pump.—29. Condensing syringe.—30. Condenser.

1. In a former part of this series some of the most conspicuous properties of the atmosphere were explained, and among these its weight and pressure.* We now propose to resume this subject, and to explain the expedients by which the weight, elasticity, and other mechanical properties of the atmosphere are ascertained.

* Common Things—Air, vol. ii. p. 1.

2. One of the most direct demonstrations of the weight of the atmosphere is afforded by the experiment, shown in all popular lectures on physics, made with the apparatus called the Bladder Glass. This is a glass cylinder of four or five inches in diameter, open at both ends, upon one end of which a piece of bladder—rendered soft and pliable by being soaked in water, is firmly tied, the wet edges of the bladder adhering to the outside surface of the glass, and to its edge, so as to be in complete air-tight contact with it. The end of the cylinder which remains uncovered is then smeared at the edges with lard, and placed upon the plate of an air-pump, the lard rendering its contact with the plate air-tight. The air-pump, which will be described in another part of this number, is nothing more than a syringe conveniently mounted, by which the air can be partially or almost wholly extracted from any close vessel, the mouth of which is applied upon the plate.

Let us suppose then, that by the action of the pump, a part of the air included under the bladder is withdrawn, the pressure of the air thus rarefied will be less than that of the external air, which is not so rarefied, and consequently the bladder being pressed with more force downwards than upwards, will yield to the excess of downward force, and will become concave. If by the constant action of the pump more and more of the air be withdrawn, the excess of the downward force becoming greater and greater, the bladder, if it have not sufficient strength to support the increased pressure, will burst inwards with an explosion as loud as that produced by the discharge of a large pistol.

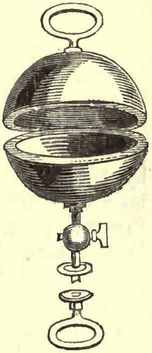
3. The same effect will be produced in whatever direction the mouth of the bladder-glass be presented, showing that the pressure of the external atmosphere acts upon the bladder equally in all directions downwards, laterally, obliquely, and upwards.

4. Even to those who admit the great weight of a column of the atmosphere, extending from the surface of the earth to the highest limit of that fluid, this experiment performed in a room often seems astonishing and inexplicable; for however weighty may be a column of air which extends upwards to the top of the atmosphere, it cannot be understood how a column extending upwards only to the ceiling of the room can have so great a weight. It is certain that water is much heavier than air, and that a column of that liquid as high as the ceiling would not have a weight at all comparable to that which bursts the bladder.

This difficulty is explained by the common effect of fluidity, by which pressure is equally and freely transmitted in all directions through the fluid, which property was illustrated by the experiment with the bottle described in our Tract on Air,* already quoted. The air included in a room is not *directly* under the pressure of a column of atmosphere extending indefinitely upwards; but it is compressed at all the openings by which it enters the room by the external air, and this pressure, which proceeds from the incumbent weight of such an atmospheric column outside the room or building, being freely transmitted inwards, the air in the room is affected by it in exactly the same manner, and to exactly the same degree, as if it were placed immediately under the incumbent weight of a column extending to the top of the atmosphere.

5. There is another familiar experiment which illustrates in a striking and instructive manner the atmospheric pressure, and which is known as that of the Magdeburg hemispheres. The apparatus known by this title is represented in fig. 1. It consists of two hollow brass hemispheres with evenly ground edges, which admit of being brought into air-tight contact when smeared with lard. The apparatus when secured upon the plate of an air-pump may be exhausted, so that the space within the hemispheres may be rendered a partial vacuum. The external air will thus press the two hemispheres together with a force proportional to the difference between the pressure of the external air and the pressure of the rarefied air within. When a sufficient exhaustion has been produced, the stopcock attached to the lower hemisphere is closed, the apparatus is unscrewed from the pump-plate, and a handle screwed upon the lower hemisphere. It will be found that two of the strongest men will be unable to tear the hemispheres asunder, provided they are of a moderate magnitude, owing to the amount of the pressure with which they are held together. If, for example, the pressure of the rarefied air within is equivalent to a column of two inches of mercury, while the external air has a pressure represented by 30 inches of mercury, there will be a force amounting to 14 lb. per square inch on the section of the hemispheres.

Fig. .



If the hemisphere have 4 inches diameter, the area of their section will be $12\frac{1}{2}$ square inches, and consequently the force with which they will be pressed together will be

$$12\tfrac{1}{2} \times 14 = 175\,\text{lb}.$$

This apparatus derives its name from the place where the inventor of the air-pump, Otto Guericke, first exhibited the

* Vol. ii., p. 4.

experiment, in the year 1654. The section of the hemispheres employed by him measured 113 square inches, and they were held together by a force equal to about three-fourths of a ton.

Since the atmosphere envelopes the earth, extending everywhere above its surface to nearly the same height, it presses upon every part of the surface, upon the surfaces of extensive continents and islands, as well as upon those of oceans and seas, with the same force as that which it is shown to exert upon the bladder-glass, and the Magdeburg hemispheres.

6. Let one end of a glass tube be plunged in a vessel of water, and let the air be partially drawn from the other end by the suction of the mouth applied to it. It will be immediately observed that water will enter the tube, and will rise in it higher and higher the more air is drawn from it by the mouth. This simple experiment, so often made in the sport of children, supplies means of weighing a column of air extending from the surface of the earth to the top of the atmosphere, with as much precision as if that column could be placed in the dish of a balance, and counterpoised by equivalent weights. The water ascends in the tube, because the pressure of the air within the tube being diminished by the suction of the mouth, is less than the pressure of the air upon the surface of the water in the vessel. This latter pressure therefore predominating, forces the water up to a certain height in the tube. The weight of the column of water which thus ascends in the tube, is exactly equal to the excess of the weight of a corresponding column of air, extending from the surface to the top of the atmosphere, over the pressure of the air remaining in the tube; and it follows, that if the tube were long enough, and if, by the suction of the mouth, all the air could be withdrawn from it, a column of water would rise in the tube whose weight would be exactly equal to that of a corresponding column of the air, extending from the surface to the top of the atmosphere.

7. Now this experiment was actually made by Pascal, at Rouen, in 1646. A tube was procured, measuring 46 feet in length, but as the suction of the air from it was then considered impracticable, the difficulty was surmounted by first closing the tube at one end, and then completely filling it with water. The upper end being then well corked, so as to prevent the escape of the water, the tube was inverted by means of ropes and pulleys properly attached to it, and the corked end being immersed in a reservoir of water, and the tube being erected to the vertical position, the cork was taken out. Immediately the column of water in the tube subsided; but instead of falling altogether out of it into the reservoir, as many expected would happen, it remained suspended at a height of about 34 feet above the level of

the water in the reservoir; the other 14 feet of the tube remaining empty.

It followed, therefore, that the column of water, 34 feet high, exactly balanced a corresponding column of air extending from the surface to the top of the atmosphere.

It appears, therefore, from the result of this celebrated experiment, that every part of the surface of the globe, whether it be land or water, and of the surface of every object upon the globe, is subject to the same pressure as if it were at the bottom of a reservoir of water 34 feet deep.

8. When we look back upon the progress of physical discovery during former ages in this department of knowledge, and consider the numerous phenomena which were constantly offered by Nature herself to the least attentive and the least acute, it cannot fail to excite surprise, that the grosser and more obvious properties of that universally diffused fluid which everywhere surrounds us, and of which mankind in every age and country have so largely availed themselves for the uses of life, should remain not only undiscovered but altogether misapprehended. Even those who claimed the rank and title of philosophers seemed to have turned aside from the plain path of discovery pointed at by the finger of Nature, and with a perverseness and fatal obstinacy devoted their faculties to the invention of fanciful theories and hypotheses, having so little analogy to truth or nature, that the bare statement of them now seems grotesque.

The ancient philosophers observed, that in the instances which commonly fell under their notice space was always filled by a material substance. The moment a solid or a liquid was by any means removed, immediately the surrounding air rushed in and filled the place which it deserted: hence they adopted the physical dogma that *Nature abhors a vacuum.* Such a proposition must be regarded as a figurative or poetical expression of a supposed law of physics, declaring it to be impossible that space could exist unoccupied by matter.

Probably one of the first ways in which the atmospheric pressure presented itself was by the effect of suction with the mouth, above described. This phenomenon was accounted for by declaring that "nature abhorred a vacuum," and that she therefore compelled the water to enter the tube and fill the space deserted by the air.

The effects of suction by the mouth led by a natural analogy to suction by artificial means. If a cylinder be open at both ends, and a piston playing in it air-tight be moved to the lower end, upon immersing this lower end in water, and then drawing up the piston, an unoccupied space would remain between the piston and the water. "But nature abhors such a space," said the ancients, "and therefore the water will not allow such a space to remain unoccupied: we find accordingly that as the piston rises the water follows it." By such fantastical theory pumps of various kinds were constructed.

9. The antipathy entertained by Nature against an empty space served the purposes of philosophy for a couple of thousand years, when it happened in the time of Galileo, that is, about the middle of the seventeenth century, that some engineers near Florence, being employed to sink a pump to an unusual depth, found they could raise by no exertion the water higher than 32 feet in the barrel. Galileo was consulted, and it is said, that he answered, half seriously, half sportively, that nature's abhorrence of a vacuum extended to the height of 32 feet, but that beyond this her disinclination to an empty space was not carried. The answer, however, whatever it was, does not appear to have been satisfactory, and the question continued to excite attention.

10. After the death of Galileo, Torricelli, his pupil, since become so celebrated, directed his attention to its solution. He argued, that whatever be the cause which sustains a column of water in a pump, the measure of the power thus manifested must be the weight of the column of water sustained: and, consequently, if another liquid were used, heavier bulk for bulk than water, the same force would sustain a column of that liquid, having less height in proportion as its weight would be greater. By using a heavier liquid, therefore, such as mercury, for example, the column sustained would be much shorter, and the experiment would be more manageable. The weight of mercury being bulk for bulk about 13½ times that of water, it followed that, if the force imputed to a vacuum could sustain 34 feet of water, it would necessarily sustain 13½ times less, or about 30 inches of mercury. Torricelli therefore made the following experiment, which has since become so memorable in the history of physical science.

He procured a glass tube A B, fig. 2, more than 30 inches long, open at one end, A, and closed at the other, B. Filling this tube with mercury, and applying his finger at the open end A, so as to prevent its escape, he inverted it, plunging the end A into mercury contained in a cistern, C D, fig. 2.

On removing the finger, he observed that the mercury in the tube fell, but did not fall altogether into the cistern; it only subsided until its surface E was at a height of about 30 inches above the surface of the mercury in the cistern.

This result, which was precisely what Torricelli had anticipated, clearly demonstrated the absurdity of the statement imputed to Galileo, that Nature's abhorrence of a vacuum extended to the height of 32 feet, since in this case her abhorrence was limited to 30 inches. In fine, Torricelli soon perceived the true cause of this phenomenon.

The weight of the atmosphere acting upon the surface of the mercury in the cistern supports the liquid in the tube. But the surface E being excluded from contact with the atmosphere, is free from the pressure of its weight; the column, therefore, of mercury F, being pressed upwards by the weight of the atmosphere, and not being pressed downwards by any other force, would stand in equilibrium.

This explanation was further confirmed by the fact, that on admitting the air to the upper end of the tube B, by breaking off the glass at that point, or opening a stop-cock placed there, the column of mercury in the tube instantly dropped into the cistern. This was precisely the effect which ought to ensue, inasmuch as the admission of the pressure of air upon the column E balanced the pressure on the surface in the cistern, and there was no longer any force to sustain a column of mercury in the tube, and consequently it fell into the cistern.

Fig. 2.

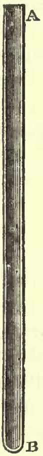
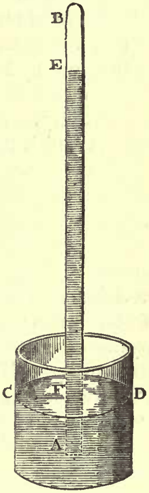


Fig. 3.



11. This experiment and its explanation excited, at the epoch we refer to, the greatest sensation throughout the scientific world, and, like all new discoveries which have a tendency to explode long-established doctrines, was rejected by the majority of scientific men. The celebrated Pascal, who flourished at that epoch, however, had the sagacity to perceive the force of Torricelli's reasoning, and proposed to submit his experiment to a test which must put an end to all further question about it. "If," said Pascal, "it be really the weight of the atmosphere under which we live that supports the column of mercury in Torricelli's tube, we shall find, by transporting this tube upwards in the atmosphere, that in proportion as it leaves below it more and more of the air, and has consequently less and less above it, there will be a less column sustained in the tube, inasmuch as the weight of the air above the tube, which is declared by Torricelli to be the force which sustains it, will be diminished by the increased elevation of the tube."

Pascal therefore caused Torricelli's tube to be carried to the top of a lofty mountain, called the Puy-de-dôme, in Auvergne, and the height of the column to be correctly noted during the ascent. It was found, in conformity with the principle announced by Torricelli, that the column gradually diminished in height as the elevation to which the instrument was carried increased. The experiment being repeated upon a high tower in Paris with like success, there no longer remained any doubt of the fact, that the column of mercury in the tube, as well as the column of water in common pumps is sustained, not by the force vulgarly called suction, nor by Nature's abhorrence of a vacuum, but simply by the weight of the incumbent air acting in one case on the surface of the mercury, and in the other on the surface of the water in the well, in which the pump terminates.

12. The instrument which we have here described, as used in the experiment of Torricelli, is nothing more than the common barometer.

The methods of constructing and mounting it so as to adapt it for use, and the precautions necessary to ensure the certainty and precision of its indications, will be explained in another number of this series; meanwhile it will be sufficient for the present to assume generally, that the mercurial column E F, suspended in the glass tube equilibrates with, and therefore measures the weight of a corresponding column of the atmosphere, extending from the surface, C F, of the mercury in the cistern indefinitely upwards.

It has been shown,* that air in its usual state is 772½ times lighter than water. But water being 13½ times lighter than mercury, it follows that air must be 13½ times 772½ times lighter than mercury. By multiplying 772½ by 13½, we obtain 10429. It follows, therefore, that 10429 cubic inches of air are equal in weight to 1 cubic inch of mercury.

13. If the atmosphere, in ascending from stratum to stratum, had constantly the same density, so that each cubic inch of air, at all heights, would have the same weight, we could at once determine its entire height by the preceding experiment; for since a column of mercury, 30 inches, or 2½ feet high, has the same weight as a column of air extending from the surface of the ground to the top of the atmosphere, and since the weight of the mercury, bulk for bulk, is 10429 times greater than that of air, it is evident that the height of a column of air as heavy as the column of mercury, must be 10429 times greater than that of the column of mercury, and would therefore be 10429 times 2½ feet, that is 26072 feet, or 5 miles very nearly.

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* Vol. ii., p. 3.

Are we then to infer, that the height of the atmosphere is really not more than 5 miles? We have a thousand evidences to the contrary. The height of the summit of the mountain called Dhwalagiri, one of the Himalaya chain, has been ascertained to be 28000 feet, and clouds are seen suspended in the air far above it. The atmosphere therefore extends to a height far above 26000 feet.

14. This height of 5 miles is that which would limit the atmosphere, if air were such a fluid as water, so that stratum might be heaped upon stratum to any height, without producing any compression in the lower strata by the effect of the weight of the superior strata. Air, however, is not such a fluid. It is, as has already been shown,* compressible without limit, and not only compressible but expansible. The air around us which composes the lowest stratum of the atmosphere, is compressed by the entire weight of the series of strata of air which are above it, and this weight, as has been already shown, amounts to 15 lb. upon a square inch of surface. Now, if any portion of this air be subjected to double that pressure, it will be contracted into half its bulk, and will consequently have twice its density; and if, on the other hand, it be relieved of half the pressure, it will expand into twice its bulk, and will consequently have only half the density. In a word, the state of air as to density will depend upon the pressure to which it is subjected. If that pressure be augmented or diminished, the density of the air will be augmented or diminished in exactly the same proportion.

15. Air being therefore elastic, and consequently indefinitely compressible and expansible, it follows that, as we ascend in the atmosphere from stratum to stratum, the density must be continually diminished, because the quantity of air above each successive stratum, being continually less, the weight pressing on the strata is continually less, and consequently the density must be proportionally less.

Hence it is apparent that the actual height of the atmosphere must be vastly greater than five miles. If the atmosphere, in ascending, were imagined to be resolved into a number of layers, each of which would contain the same weight of air, these layers would increase in thickness in ascending. Thus, if the lowest layer were 10 feet thick, a layer at such a height that half the entire atmosphere was below it, would be 20 feet thick, because being subject to only half the pressure it would have only half the density, and would therefore occupy twice the bulk. In like manner, a layer at such a height as would leave three-fourths of the atmosphere below it, being pressed upon by the weight of only one-fourth, would have a thickness of 40 feet, and so on.

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* Vol. ii., p. 5.

The air, therefore, in ascending, becomes continually and indefinitely thinner and rarer. Persons who have ascended to great heights in balloons or on mountains, have accordingly found themselves in an atmosphere so rarefied as to derange seriously the vital functions.

16. The various phenomena vulgarly called suction are nothing more than so many various effects of the atmospheric pressure.

17. If a piece of moist leather be placed in close contact with any heavy body having a smooth surface, such as a stone or a piece of metal, it will adhere to it; and if a cord be attached to the leather, the stone or metal may be raised by it.

This effect arises from the exclusion of the air from between the leather and the stone. The weight of the atmosphere presses their surfaces together with a force amounting to 15 lb. on a square inch of the surface of contact.

18. The power of flies, and other insects, to walk on ceilings, smooth pieces of wood, and other similar surfaces, in doing which the gravity of their bodies appears to have no effect, is explained upon the same principle. Their feet are provided with an apparatus similar exactly to the leather applied to the stone.

19. The pressure and elasticity of the air are both called into effect in the act of respiration. When we inspire the atmosphere, we make by a muscular exertion an enlarged space within the chest. The atmospheric pressure forces the external air into this space. By another and contrary muscular exertion, the chest is then contracted, so as to squeeze out the air which has been inhaled, and which, by compression, acquires an elasticity greater than the atmospheric pressure, in virtue of which it is forced out at the mouth and nostrils.

20. The action of a common bellows is precisely similar, except that the aperture through which the air enters is different from that by which it is expelled. The analogy, however, would be complete if we inspired by the mouth and expelled by the nose. When the boards of the bellows are separated, the inner chamber is enlarged, and the air is forced in by the external pressure through the aperture governed by the leather valve or clack. The boards being then pressed together, and the escape of the air being stopped by the closed valve, it is compressed until it acquires an elasticity greater than the atmospheric pressure, and is forced out.

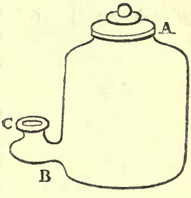
Bellows on a large scale are constructed with an intermediate board, so as to consist of two chambers, and to produce a continued instead of an intermittent blast. This is nothing more than a double bellows, one forcing air into the chamber of the other, and the second being urged by an uninterrupted pressure produced usually by a weight suspended from the upper board.

21. The effect produced by a vent-peg in a cask of liquid is explained by the atmospheric pressure. The cask being air-tight, so long as the vent-peg is maintained in its position, the surface of the liquid in the vessel will be excluded from the atmospheric pressure, and it can only flow from the cock in virtue of its own weight. If the weight of the atmosphere be greater than the weight of a column of the liquid, corresponding with the depth of the liquid in the vessel, the liquid cannot flow from the cask; but the moment the vent-peg is removed, the atmospheric pressure being admitted above the level of the liquid in the cask, the liquid flows from the cock in virtue of its own weight.

If the lid of a teapot or kettle were perfectly close, the liquid would not flow from the pipe, because the atmospheric pressure would be excluded from the inner surface. A small hole is therefore usually made in the lid to admit the air and allow the liquid to flow freely.

22. Ink-bottles are sometimes so constructed as to prevent the inconvenience of the ink thickening and drying. Such a bottle is represented in fig. 4: A B is a close glass vessel, from the bottom of which a short tube B C proceeds, the depth of which is sufficient for the immersion of a pen. When ink is poured in at C, the bottle being placed in an inclined position, is gradually filled up to the knob A. If the bottle be now placed in the position represented in the figure, the chamber A B being filled with the liquid, the air will be excluded from it, and the pressure tending to force the ink upwards in the short tube C, will be equal to the weight of the column of ink, the height of which is equal to the depth of the ink in the bottle A B, and the bore of which is equal to the section of the tube C. The ink will be prevented from rising in the tube C by the atmospheric pressure, which is much greater than the pressure of the column of liquid in the bottle. As the ink in the short tube C is consumed by use, its surface will gradually fall to a level with the horizontal tube B, a small bubble of air will then insinuate itself through B, and will rise to the top of the bottle A B, where it will exert an elastic pressure, which will cause the surface of the ink in C to rise a little higher; and this effect will be continually repeated, until all the ink in the bottle has been used.

Fig. 4.



Birdcage fountains are constructed on the same principle.

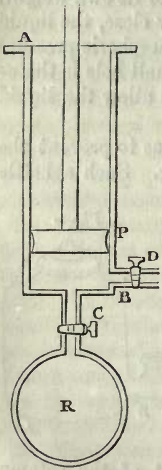
The peculiar gurgling noise produced in decanting wine arises from the pressure of the atmosphere forcing air into the interior of the bottle to replace the liquid which escapes.

23. The common syringe by which air is withdrawn from or condensed in any vessel derives its efficacy altogether from this property of the elasticity of air.

The instrument is called an exhausting or condensing syringe, according as it is adapted to extract air from a vessel, or to force air into it.

24. To explain the principle of the exhausting syringe, let A B (fig. 5) represent a cylinder having a solid piston P, moving air-tight in it. Let C be a tube proceeding from its lower end, furnished with a stop-cock C, and let B be another tube furnished with a stop-cock D. Let the tube C be screwed upon any vessel such as R, from which it is desired to extract the air.

Fig. 5.



If the piston be now raised in the cylinder, the cock D being closed and the cock C being open, the air in R will necessarily expand, in virtue of its elasticity, so as to fill the enlarged space provided by raising the piston. The air which previously filled the vessel R and the connecting tube will, in fact, now fill these, and also the enlarged space in the cylinder. When the piston is brought to the top of the cylinder, let the cock C be closed and the cock D be opened. Upon driving down the piston, the air which fills the cylinder will be expelled from the tube B through the open stop-cock D. When the piston has reached the bottom of the cylinder, let D be closed and C opened, and let the same process be repeated; the air filling the vessel R will, as before, dilate itself, so as to fill such vessel and the cylinder. The cock C being again closed, and D opened, and the piston driven down, the air which fills the cylinder will be again expelled. This process being continued, any desired quantity of air can be taken out of the vessel R and expelled into the atmosphere.

It is evident that the escape of the air from R into the cylinder is effected in virtue of its elasticity; while its escape from the stop-cock D into the atmosphere is effected in virtue of its compressibility.

25. It is easy to explain the *rate* at which the air is drawn

from the vessel R by this process. If we suppose the volume of the cylinder through which the piston passes to be $\frac{1}{10}$th, for example, of the entire volume of the cylinder the tube and the connecting pipe taken together, then it is clear, that on completing the first downward stroke of the piston, $\frac{1}{10}$th of all the air included between the piston and the surface of the vessel R will be expelled, and $\frac{9}{10}$ths will consequently remain.

At every succeeding stroke, $\frac{1}{10}$th of what remained after the preceding stroke will be expelled, and in the same way $\frac{9}{10}$ths will remain.

If we suppose the vessel R and the connecting tube to contain ten million grains weight of air, the quantities expelled at each successive stroke, the quantities remaining, and the total quantities expelled from the commencement of the operation, will be thus exhibited in the following table :—

No. of Strokes.	Grains expelled at each stroke.	Grains remaining under pressure.	Total number of grains expelled.
1	1,000000	9,000000	1,000000
2	900000	8,100000	1,900000
3	810000	7,290000	2,710000
4	729000	6,561000	3,439000
5	656100	5,904900	4,095100
6	590490	5,314410	4,685590
7	531441	4,782969	5,217031
8	478297	4,304672	5,695328
9	430467	3,874205	6,125795
10	387421	3,486784	6,513216
11	348678	3,138106	6,861894
12	313811	2,824295	7,175705

Thus, in twelve strokes of the syringe, of the ten million of grains of air originally included, something more than seven million, or seven-tenths of the whole, have been withdrawn, and something less than three-tenths remain.

26. A rarefaction has been therefore produced in the proportion of something more than three to ten. But it will be apparent, that although by this process the rarefaction may be

continued to any required extent, a literal and absolute vacuum can never be produced, because some quantity of air, however small, must always remain in the vessel R. After every stroke of the piston, nine-tenths of the air which is in the vessel before the stroke remains in it. Now it is evident, that if we successively subtract one-tenth of any quantity, we must always have some remainder, however long the process be continued; and the same will be true, whatever proportion be thus continually subtracted.

27. Nevertheless, although an absolute vacuum cannot be obtained by such means, we can continue the process until the rarefaction shall be carried to any required extent.

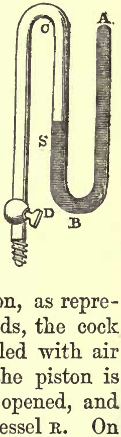
In practice, the stop-cocks D and C are replaced by valves. A valve is placed at D which, opening outwards, is forced open by the elasticity of the air compressed under the piston when depressed, but is kept closed by the external pressure of the atmosphere when the piston is raised. The valve at C opens upwards, and is opened by the elasticity of the air in R when the piston is raised, and kept closed by the elasticity of the compressed air in the cylinder when the piston is depressed. Instead of placing a tube and valve at B, it is usual to make the valve in the piston itself, opening upwards; but the action is still the same. An exhausting syringe, therefore, may be shortly described to consist of a cylinder with two valves, one in the bottom, opening upwards, and one in the piston, also opening upwards. When the piston is drawn upwards, the valve in the bottom of the cylinder is opened by the pressure of the air under it, and the air passes through it. When the piston is driven downwards, the valve in the piston is opened by the elasticity of the air compressed under it, which rushes through it.

28. The air-pump is an apparatus consisting usually of two exhausting syringes, B B′, fig. 6, mounted so as to be worked by a single winch and handle, as represented at D, and communicating by a common pipe T with a glass vessel R, in which may be placed the objects of experiment. The vessel R, called a receiver, has an edge S, ground smooth, resting upon a plate, also ground smooth, and kept in air-tight connection with it by being smeared with hog's lard. A stop-cock C is provided in the pipe T, by which the communications between the receiver R and the syringes can be made and broken at pleasure. Another stop-cock is provided elsewhere, by which a communication can be made at pleasure between the interior of the receiver R and the external air. To indicate the extent to which the rarefaction is carried from time to time by the operation of the syringes, a mercurial gauge H G M is provided, constructed in all respects similar to a

barometer. The atmosphere presses on the surface of the mercury in the cistern M, while the column of mercury in the tube H G is pressed upon by the rarefied air in R. The height of the column, therefore, sustained in the tube, indicates the difference between the pressure of the external air and the air in the receiver.

When a gauge, of the form represented in fig. 6, is used, it is necessary that it should have the height of about 30 inches, since, when a high degree of rarefaction has been effected, a column of mercury will be sustained in the tube H G, very little less than in the common barometer. In small pumps, where this height would be inconvenient, a siphon-gauge, such as that represented in fig. 7, is used. This gauge is screwed on to a pipe communicating with the receiver. Mercury fills the leg A B, which is closed at the top A, and partially fills the legs S. When the atmosphere communicates freely with the tube D C, the surface of the mercury in S being pressed by its full force, sustains all the mercury which the tube B A can contain, and this tube, consequently, remains completely filled; but when the pipe D C S is put in communication with the exhausted receiver, the surface of the mercury in S being acted upon only by the pressure of the rarefied air in the receiver, the weight of the higher column in B A will predominate, and the mercury will fall in it, until the difference of the levels in the two legs shall be equal to the pressure of rarefied air in the receiver.

Fig. 7.



29. The condensing syringe differs from the exhausting syringe only in the direction in which the valves are placed. It consists of a cylinder and piston, as represented in fig. 5. When the piston is drawn upwards, the cock D is open, and C is closed, and the cylinder is filled with air proceeding from the external atmosphere. When the piston is pressed downwards, the cock D is closed and C is opened, and the air which filled the cylinder is forced into the vessel R. On raising the piston again, the cock C is closed and D is opened, and the effects take place as before. It is evident that, by every stroke of the piston, as much air as fills the cylinder is driven into the vessel R.

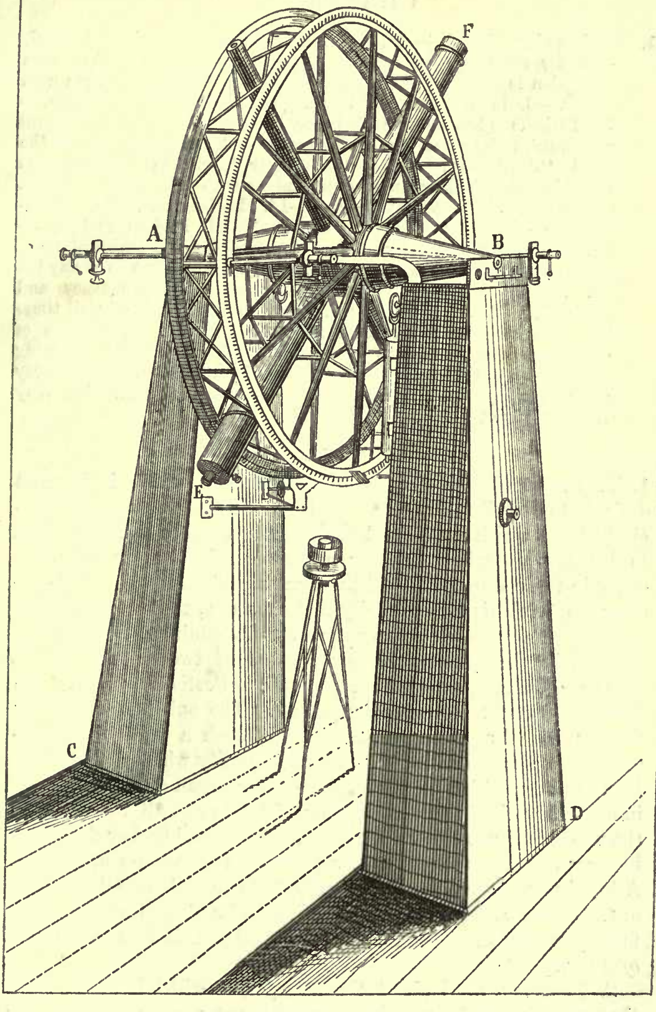
In practice, the cocks D and C are replaced by two valves, one in the bottom of the cylinder, and the other in the piston, both opening downwards, contrary to the valves in the exhausting syringe.

The operation is explained in the same manner.

30. The condenser is an apparatus which bears to the con-

densing syringe precisely the same relation which the air-pump bears to the exhausting syringe. It consists of one or two condensing syringes, mounted so as to be conveniently worked by a winch, and communicating with a strong reservoir, which is fastened down upon a plate, so as to be maintained in air-tight contact with it, notwithstanding the bursting pressure of air condensed within it. By the operation of syringes, volumes of air corresponding to their magnitude are forced continually into the reservoir, which becomes therefore filled with an atmosphere proportionally more dense than the external air.

Fig. 1.



COMMON THINGS.

TIME.

CHAPTER I.

1. Simple notions difficult to define.—2. Conception of Time, how obtained. —3. By succession of sensible impressions.—4. Proof that such succession is necessary.—5. Time passes faster with some than with others.—6. Is measured only by a regular and uniform succession.—7. Periodic phenomena which may measure time. — 8. Natural appearances intended for that purpose.—9. Significations of the word "day."—10. Hours.—11. Their length in certain cases variable.—12. Vulgar and equinoctial hours.—13. Commencement of the day with different nations.—14. Italian time.—15. Inconvenience of such a mode of reckoning. — 16. Modern method. — 17. Civil and astronomical time.—18. The day the standard unit. —19. Necessary to determine it rigorously.—20. What is a day?—21. Diurnal rotation of the heavens.—22. Its constancy and uniformity.—23. Nevertheless not fitted to be the unit of civil time. 24. The meridian.—25. Diurnal motion of the sun—means of observing it.—26. Transit instrument.—27. Method of observing with it.—28. Sidereal day—its subdivisions.—29. Its permanency and uniformity—unfit, nevertheless, for a measure of time.—30. Why the sun is not fit.

I.—TIME IN GENERAL.

1. The most simple of our notions are those which it is most difficult to describe or define. It is fortunate that they are precisely those which least need definition. Geometers have failed in defining a straight line, or a plane surface, but no persons differ in their conceptions of the meaning of these terms. Locke observes, with his usual felicity and clearness, that a word which expresses a simple idea does not admit of definition, inasmuch as a definition being a sentence composed of two or more words having different significations, cannot collectively express one idea which has no composition at all. The only way to convey to the mind of another, the meaning of such a word, is by presenting to his senses the object or the quality which it expresses. In that case, if he possess the necessary organ of sense, he will immediately obtain the perception; if he do not all the words in the world will not convey it to him. A person blind or deaf from infancy can never acquire any perception of colours or sounds. A blind man after listening attentively to an elaborate description of the colour *scarlet*, declared that he had a very clear and satisfactory notion of it, and that he considered it like the *sound of a trumpet!*

2. Time is a word about the meaning of which it would seem that there could be no disagreement; yet we cannot as in the case of words expressing sensible ideas refer to any external object from which we can immediately receive the perception which that word expresses. Although we cannot define by words

the meaning of the terms white or red, we can point to the lily and the rose, and thus supersede verbal definition. We cannot define the notes of the nightingale or the lark, but if we walk forth in the night or at the early dawn, the one or the other will discourse music more eloquent than definition.

Can we then, by a like appeal to the senses, obtain a notion of what is expressed by the word TIME? Which organ does it address? Time cannot be seen, heard, felt, tasted or smelled. It cannot be seized and submitted to observation and analysis. It is the most fleeting of all perceptions. Moment follows moment in never ceasing succession, but no moment can be said to have any continued existence, so as to be submitted to contemplation.

3. Metaphysicians differ as to the mental process by which we acquire a perception of duration, but they agree generally that its origin is closely connected with the succession of our thoughts and ideas. From our observation and consciousness of this succession, and from that alone, does our original conception of time proceed. When the mind has once been stored with ideas and perceptions derived by the senses from external objects, the memory can at will reproduce them and marshal them in infinitely various series before the imagination. Of such succession of thoughts and feelings thus evoked by memory we are as distinctly conscious as we are of those derived directly from external objects, and by that consciousness we acquire a perception of time when no external objects are presented to the senses. Thus if during the darkness of night we lie awake, a constant succession of thoughts and images pass through the mind, consisting altogether of various ideas and combinations supplied by the memory. This succession of notions creates a consciousness from which we derive a perception of a certain lapse of time.

4. That an actual succession of thoughts, emotions, ideas or images, whether they proceed directly from external objects or arise from the operations of memory, reflection, or imagination, is absolutely necessary to our perception of time is demonstrated by the fact that whenever such succession ceases, our perception of time ceases with it. Thus in profound sleep without dreaming, we have no perception whatever of duration. Having gone to sleep at night, and waking, in the morning it is true that we know that a certain definite interval has elapsed, but we derive this knowledge by inference from external phenomena and not at all from consciousness. We see that the darkness of night has changed to the light of day; that the sun which was below the horizon is above it, and we know by past experience that these changes are only produced in a certain interval of time, and

that such interval of time must have elapsed since we fell asleep. But if we fall asleep in the evening and do not awaken until the next day but one, we are unconscious of the lapse of more than one night. Robinson Crusoe, alone on the desert island, being indisposed, swallowed a narcotic composed of rum and the infusion of tobacco, which threw him into a profound sleep that continued from the night until the afternoon of the next day but one, and he was unconscious of the lapse of more than a single night. He found accordingly, when liberated from his solitary abode, upon comparing his journal with the actual dates, that he had lost a day in his account.

5. It might, therefore, be naturally inferred that the succession of our thoughts or mental impressions, being the origin of our perception of duration, would be necessarily a measure of duration, and indeed the only measure of it. It is easy, nevertheless, to see that such an inference can only be admitted with considerable qualification. The succession of sensible impressions produced by certain regular and uniform series of external appearances is unquestionably an exact and the only exact measure of time, but it would be, on the other hand, a grave error to assume that such a just measure of duration can result indifferently from every series of mental impressions. Who does not know that a series of agreeable thoughts and brilliant ideas has the effect of making time pass with unwonted rapidity?

"Too late I stayed. Forgive the crime!
Unheeded flew the hours.
How noiseless falls the foot of Time
Which only treads on flowers!

"Ah! who with clear account remarks
The ebbing of his glass,
When all its sands are diamond sparks,
Which dazzle as they pass?"

Again,—the series of our thoughts becomes a most fallacious measure of time when we are the sport of the more exciting passions and emotions, such as hope, fear, or despair.

"*Rosalind.* Time travels in divers paces with divers persons; I'll tell you who time ambles withal, who time trots withal, who time gallops withal, and who he stands still withal.

"*Orlando.* I prythee, who does he trot withal?

"*Ros.* Marry, he trots hard with a young maid, between the contract of her marriage, and the day it is solemnised. If the interim be but a se'nnight, time's pace is so hard, that it seems the length of seven years.

"*Orl.* Who ambles time withal?

"*Ros.* With a priest that lacks Latin, and a rich man that hath not the gout: for the one sleeps easily, because he cannot study, and the other lives merrily, because he feels no pain; the one lacking the burden of lean and wasteful learning, the other knowing no burden of heavy tedious penury. These time ambles withal.

"*Orl.* Who doth he gallop withal?

"*Ros.* With a thief to the gallows: for though he go as softly as foot can fall, he thinks himself too soon there.

"*Orl.* Who stays it withal?

"*Ros.* With lawyers in the vacation: for they sleep between term and term, and then they perceive not how time moves."

SHAKSPEARE, *As You Like It*, Act III. Scene 2.

6. A succession of thoughts and perceptions floating at hazard through the mind, or excited casually and without regularity by external objects, produces a perception of time, but affords no measure of it; just as the general view of a landscape produces the impression of a certain progression of distances among the objects composing it, without, however, supplying the means of estimating with numerical precision such distances.

A progression of events or perceptions which would supply a measure of time, must be absolutely uniform and regular. In such case the number of repetitions of the same event or phenomenon found between any two points of the series becomes the measure of the interval of time which has elapsed between them.

7. The series of phenomena adopted by mankind as measures of time have been either natural or artificial. Natural measures of time consist of regularly recurring periodical phenomena, which are easily and universally observable by all the world, and which never cease to be reproduced with the same uniformity in all parts of the inhabited globe. Artificial measures are usually motions which are so contrived as to be uniform so long as they continue, and which, when exhausted, admit of being restored.

Any regular periodical change, however, may serve as a measure of time. Thus woodmen ascertain the age of certain trees by marks upon their trunks. The ages of certain species of cattle are indicated by the successive formation of rings on their horns. The age of horses is ascertained by the successive disappearance of marks from their teeth.

If a candle in burning were consumed uniformly its decrease of length might be used as a measure of time. In certain sales by auction, the continuance of the bidding was limited by "inch of candle."

8. But the periodical phenomena which have been most universally adopted in all ages and all countries as measures of time, are those which were expressly assigned for that, among many more important purposes, by the Omniscient, who, when he "made the firmament and saw that it was good," said—

"Let there be light in the firmament of the heaven, to divide the day from the night; and let them be for signs, and for seasons, and for days, and years:

"And God made two great lights; the greater light to rule the day, and the lesser light to rule the night."—Gen. i. 14, 16.

Days, weeks, months, and years, and the subdivisions of a day, hours, minutes, and seconds, having then been adopted by mankind in general as the measures of time, and as the landmarks of history and chronology, it may perhaps be thought that little more remains to be said about the matter; that these chronometric terms used in the common intercourse of life by all peoples—

> "Familiar in their mouths as household words,"

have significations so clear, distinct, and unequivocal as to supersede the necessity of all exposition and discussion. All the world knows what a day is, and that weeks, months, and years are composed of so many of these days. We shall, nevertheless, soon render it apparent that the import of these very familiar terms is not quite so clear even in the minds of moderately well-informed persons as it is supposed to be.

II.—THE HOURS.

9. The term DAY has two distinct significations. As opposed to night, it means the interval during which we receive light from the sun. Now this interval is not very definite. According to some, it means the interval between sunrise and sunset. But according to others, it signifies the interval between the morning dawn and the termination of the evening twilight; or from the disappearance of the stars before sunrise to their reappearance after sunset.

The other sense of the word DAY is that in which it is used as a chronometric term. It is the interval of time which elapses between two successive appearances of the sun at the same point of the heavens with relation to the horizon. This interval evidently includes a day and a night.

The Greeks used a word, for which there is no English equivalent, to express this latter sense of the term DAY. This word was νυχθήμερον (*nukthemeron,*) a compound of the terms night and day.

10. From time immemorial a duodecimal division of the day has been adopted by all nations. Some peoples have counted the hours consecutively, from one to twenty-four. Others have divided the day into two series of twelve hours. It may perhaps be a legitimate subject of regret that the same system of decimal reckoning, which has conferred such simplicity upon the arithmetical

notation and terminology, should not have been applied to the counting of time. When the spirit of innovation was in the ascendant in France in 1793, such an attempt was made, the day being divided into ten hours, the hour into an hundred minutes, and the minute into an hundred seconds. The power of custom, however, prevailed over even the domination of terrorism and the project signally failed.

11. The hours into which the day was resolved were generally intended to be equal, each being the twenty-fourth part of the entire interval called a day. Nevertheless, there were some exceptions to this. Thus, at a certain epoch in Greece, the interval between sunrise and sunset was divided into twelve equal parts called hours of the day, and the other interval, between sunset and sunrise, was also divided into twelve equal parts, called hours of the night. It is evident that the diurnal hours were equal to the nocturnal hours only at the equinoxes, and that from the spring to the autumnal equinox the diurnal were longer than the nocturnal hours, and from the autumnal to the spring equinox the nocturnal were longer than the diurnal hours. The hours, both diurnal and nocturnal, were also subject to continual variation of length. From the first day of winter, or the shortest day, to the first day of summer, or the longest day, the diurnal hours constantly increased, and the nocturnal hours constantly decreased in length; and from the first day of summer to the first day of winter, the nocturnal hours constantly increased, while the diurnal hours constantly diminished.

Such a system could not be properly denominated chronometric at all, since the interval of time called an hour was different at different seasons.

12. Defective as such a method of counting time must have been for the purposes of common life, it was utterly inadmissible for any scientific investigations; and Ptolemy, in his astronomical observations, was always obliged to transform the vulgar hours into equinoxial hours; so called, no doubt, because it was only at the equinoxes that the vulgar diurnal were equal to the nocturnal hours.

How imperfect the art of measuring time was in that age, may be imagined when it is stated that, in the observations of Ptolemy, the time of astronomical phenomena is never indicated nearer the truth than a quarter of an hour. At present it is determined in good observations to less than the tenth of a second.

13. For chronometric purposes, it is not enough to fix the value of the standard unit of time. It is necessary also to establish a convention as to the moment at which each successive unit commences, and the preceding one terminates. In a word, a point of

departure must be agreed upon for each chronometric unit; and this, as will be seen, is a subject upon which much disaccord has prevailed, and the establishment of which, with all the aids afforded by the advanced state of astronomical science, has been a matter of the greatest difficulty and delicacy.

The Jews, the ancient Athenians, the Chinese, and other Oriental nations, as well as the Italians, fixed the commencement of the day at sunset. According to the Italians, even to the present times, the day is divided into twenty-four successive hours, reckoned continuously from sunset to sunset. Thus, at an hour before sunset, it is said to be twenty-three o'clock, at two hours before sunset it is twenty-two o'clock, and so on.

According to this system, the hour of sunrise varies from day to day, and from season to season, but the hour of sunset is constant, being 24 o'clock or 0 o'clock. At the equinoxes, the sun rises at twelve o'clock. From the spring to the autumnal equinoxes, it rises before twelve, and from the autumnal to the spring equinoxes, it rises after twelve.

It is evident that a clock to indicate such time must be set from day to day, or at least from week to week, since the hour of sunset would be constantly later during one half-year, and constantly earlier during the other.

14. At some places in Italy, and more particularly at Rome, public clocks are set according to this system, and others placed near them according to the common system, the indications of the one being called ITALIAN, and those of the other, FRENCH TIME.

The system of Italian time has been defended upon the ground of the convenience it affords, of always telling the hour of sunset, so as to show to travellers and those who are occupied in out-door employments the time they have at their disposition before nightfall. Against this convenience, such as it is, however, is to be considered the constant necessity from day to day of setting all the watches and clocks—an operation called by the Italians TOCCARE IL TEMPO—to touch the time. There are other obvious inconveniences, however, attending such a system, such as the constant variation of the hours of meals, of going to bed and rising, of all descriptions of regular labour, the hours of opening and closing all public offices, of commencing and terminating all public business, &c. Nevertheless, such is the force of established custom, that this mode of reckoning time still prevails to a great extent in the Italian peninsula.

The Babylonians, Syrians, Persians, the modern Greeks, and the inhabitants of the Balearic Isles, took the moment of sunrise for the commencement of the day.

15. Whether the commencement of the day be fixed at sunset

or sunrise, the disadvantages indicated above must attend such a mode of reckoning time; to which it may be added, that of all diurnal phenomena, there is not one of which the observation is attended with more uncertainty and risk of error than sunrise and sunset.

16. The English, French, Germans, and generally the moderns in all the more civilised parts of the globe, commence the day at midnight, and divide it into two equal series of twelve hours, so that midday is twelve o'clock as well as midnight. According to this system of reckoning, it is necessary, whenever an hour is named, to indicate its relation to noon. The hours before noon are indicated by the letters A.M., and those after noon by P.M., being the initials of the Latin words *ante meridiem* (before midday), and *post meridiem* (after midday).

Among ancient astronomers who adopted this mode of reckoning, may be mentioned Hipparchus, who flourished about a hundred and fifty years before our era, and among moderns Copernicus.

The ancient Egyptians began the day at noon, in which they were followed by Ptolemy, a celebrated astronomer, who flourished at Alexandria in the second century of our era. This diurnal epoch has been by general consent adopted by modern astronomers, who divide the day into twenty-four successive hours, reckoned from noon to noon. Thus, according to their manner of reckoning, twenty minutes and an half after ten o'clock in the morning, would be $22^h\ 20^m\ 30^s$.

17. Civil or common time, therefore, is half a day before astronomical time, a circumstance which must always be carefully allowed for in the comparison of dates expressed according to the two modes of reckoning.

Thus, for example, the first day of the year 1854, according to civil reckoning, commenced at the moment of midnight, between the 31st December, 1853, and 1st January, 1854. But according to astronomical reckoning it commenced at midday on 1st January, 1854. It follows, therefore, that the twelve hours which preceded the noon of 1st January, 1854, were according to astronomical reckoning the last twelve hours of the year 1853.

In like manner, a certain hour of the forenoon, 5 A.M. of a day (Tuesday, for example), according to civil time, is $17^h\ 0^m\ 0^s$ of the preceding day (Monday), according to astronomical time. From noon, however, till midnight of any given day, the civil and astronomical dates are exactly the same.

III.—THE DAY.

18. A day then being adopted by common consent, and indeed by the force of things, as the standard unit for the measure of

time, all longer intervals being expressed by its multiples, and all shorter ones by its fractional subdivisions, it is above all things indispensable that its absolute length should be understood with perfect clearness, and ascertained with the most rigorous precision. Like all standard measures, it is necessary that it should have one invariable length, and that this length should be at all times capable of verification by comparison with some natural phenomena, observable at all times and places, and which, during an endless succession of ages, past and future, is subject to no change.

19. It may perhaps be thought that such extreme precision and permanency is needless, and that a departure of the standard from exactness by a very minute fraction would be for all practical purposes unimportant. If the standard, whatever it be, were only applied to the measurement of quantities which are not large multiples of itself, this might be admitted. But it is otherwise, when it forms a very minute fraction of that which it is applied to measure. An error of the ten-thousandth part of an inch in a foot may be unimportant, so long as short spaces—as, for example, the length of a room—only are in question. But, if we attempt to apply the foot to measure great distances, the small error is multiplied until it swells into one so great as utterly to vitiate the results. Thus an error of the ten-thousandth part of an inch in a foot becomes an error of more than an inch in two miles; of more than a foot in twenty-four miles; of more than a mile in 120000 miles, and so on.

If in the measurement of distance vast errors may thus arise from the indefinite increase of small inaccuracies of the standard units by multiplication and accumulation, it is much more so with respect to the measures of time, errors in which, even of the smallest amount, accumulating for ages, would involve not only astronomy but history and chronology in complete confusion. It will therefore be understood how important it is in many points of view, that we should obtain clear, distinct, and settled notions of the import of these terms,—days, weeks, months, and years,—which constitute our chronometric nomenclature.

20. What is a day, the fundamental unit of all time? In a rough and general way we have defined it to be the interval of time which elapses between two successive returns of the sun to the same point of the firmament. But to observe and ascertain with the necessary precision this interval, it is necessary to have some means of marking a certain point of the firmament; and, when so marked, of observing the exact moment at which the sun arrives at it. The sun, however, not being a mere point, but a circular space or *disc*, as it is called, of considerable apparent

magnitude, covers a certain part of the heavens, and different points of this disc arrive at a given point of the firmament at different moments ; so that when we speak of the moment the sun passes any given point of the heavens, our words have no definite meaning unless we specify what point of the sun's disc our observation is applied to. The point in question is of course the centre of the disc, the successive returns of which to a certain position in the heavens must be observed.

The point most convenient in all respects for such an observation is the highest to which the sun rises in its diurnal course across the heavens. But to render this position of the sun's centre, and the means of observing it intelligible, it will be necessary to consider the apparent diurnal motion of the heavens under a much more general point of view.

21. If we suppose an observer to stand with his back to the north, looking to the south, and consequently having the east upon his left, and the west upon his right, the sky being supposed to be cloudless for a day and a night, a remarkable spectacle will be presented to his view, the imposing grandeur of which continues to excite our admiration in spite of the familiarity which is produced by its never-ceasing presence.

The celestial vault presents the appearance of a vast hollow sphere, one half of which only is presented at any one moment to our view, the base of this visible hemisphere being the plane of the horizon, in the centre of which we stand. This hollow sphere appears to have a motion of rotation round a certain diameter as an axis, carrying with it as it revolves the countless objects, stars, planets, sun, and moon, which appear in various positions upon its stupendous concave surface. Standing in the position here described the sphere seems to revolve from left to right round an axis inclined to the horizon in a vertical plane, directed north and south. This apparent motion causes all the celestial objects to rise in succession on the left, that is on the east, and gradually rising they approach to and pass the vertical plane directed north and south, and after passing it, they descend upon the right, that is on the west, and in fine disappear below the horizon.

22. This diurnal motion of the celestial sphere is characterised by the most rigorous and absolute uniformity and constancy. It is never faster, never slower, and never stops. It has continued thus to move from time immemorial, and according to all appearance, and subject to the existing laws of nature, will continue so to move as long as the globe of the earth endures.

23. Such constancy and uniformity, combined with the fact that it is universally observable, would render such an apparent motion eminently fitted as a measure of time. Nevertheless as

will presently appear, it is attended with other circumstances which make it unsuitable for that purpose.

24. The vertical plane directed north and south, of which we have spoken, if supposed to be extended upwards to the firmament, will meet the visible hemisphere in a semicircle which, passing through the zenith, as the point directly over the observer is called, descends to the horizon at the north and south points. This semicircle is called the MERIDIAN. It divides the visible hemisphere into two equal parts, the eastern on the left of the observer, and the western on his right. By the diurnal rotation of the celestial sphere, all objects upon it rising in the east ascend to the meridian, where they attain their greatest altitude, and then descend to the west and disappear. The interval during which each of them is visible is divided into two exactly equal parts by the meridian, the time which elapses between the moment at which it rises and that at which it passes the meridian and attains its greatest altitude, being equal to that which elapses between the latter moment, and that at which it disappears.

This movement of the heavens is more observable by night than by day, because it is then shared by a vast number of objects, having positions infinitely various upon the celestial vault. Countless numbers are every moment rising or ascending towards the meridian, passing it, or descending from it, or setting. Although the objects upon the firmament by day are not less numerous, they are rendered invisible by the superior splendour of the sun. They may nevertheless be seen even then with sufficiently powerful telescopes, and they present exactly the same apparent motion, being still carried round with the common motion imparted by the celestial sphere.

25. The sun like the rest is carried round with the diurnal motion, and its continuance above the horizon is divided into equal parts by the meridian. Hence it appears that when its centre is on the meridian, it is midday or noon, and at that moment it has its greatest altitude.

This moment then being the epoch upon which the fundamental unit of time is based, it becomes of great importance to comprehend the means which have been contrived for accurately observing it. If the meridian were traced by a visible line upon the heavens, the observation of the moment at which any celestial object crosses it would be easy. But that not being the case, it may be asked how the moment at which the sun's centre passes a merely imaginary line, can be ascertained with the extreme precision necessary in this case.

26. Astronomers have accomplished this by a very simple and

admirable contrivance. They have enabled observers to mark for themselves the meridian upon the firmament with such distinctness and precision, that the moment at which any celestial object passes it can be ascertained to a small fraction of a second by direct observation.

One of the forms of instrument most easily understood by which this is accomplished is shown in fig. 1 (p. 113). The passage of any celestial object across the meridian being called a TRANSIT, instruments adapted to ascertain the moment such transits take place are called TRANSIT INSTRUMENTS. The particular form shown in fig. 1 is called a TRANSIT CIRCLE.

The instrument is mounted on two pillars, A C and B D, of solid stone, erected on a foundation of masonry presenting all the conditions necessary to guarantee the greatest firmness and solidity. These pillars stand east and west, the space between them therefore, looking north and south. A telescope E F is supported upon an horizontal axis A B, the ends of which rest in angular-shaped supports, called from their form Y's, which are established upon the summits of the two stone pillars. These supports being rendered by suitable adjustments truly horizontal, and the line joining them being directed truly east and west, the telescope when placed in an horizontal direction will point exactly north and south, and if it be turned upon its axis, so as to be successively directed to different points of the firmament, it will sweep over the celestial meridian.

Attached to the telescope is a graduated circle, consisting of two flat rims of metal, connected together in a firm manner by a system of spokes and diagonal braces. By means of this circle the altitude of any object to which the telescope may be directed can be measured; but this not being connected with our present purpose need not be further noticed. All that is now necessary to be understood is that when it is turned upon its axis, the telescope is successively directed to all points of the meridian.

When we look through the telescope, we behold a circular space upon the heavens of a certain magnitude. This space is called the FIELD OF VIEW.

The meridian is in the direction of a line which would pass vertically through the centre of this circular space, dividing it into two equal parts, one to the right, and the other to the left. The celestial objects, as they are carried by the diurnal motion of the sphere, pass from east to west across the meridian, moving in a direction apparently horizontal. Such of them, therefore, as may come within the limits of the field of view, in any one position of the telescope, will appear to pass across the field in horizontal lines; and if the observer were provided with any means of ascertaining the moment at which an object is precisely halfway between the point at which it enters and that at which it leaves the field of view, he would know the moment at which it passed the meridian.

This is accomplished by a very simple and admirable contrivance. In the eye-piece of the telescope is fixed a small frame, across which are extended vertically five or seven fine wires or filaments at equal distances apart, the centre one passing through the middle of the field of view, and one horizontal wire also passing through the centre, and therefore dividing all the vertical wires equally.

The field of view and the system of wires are shown in fig. 2, (p. 129), where E W is the horizontal, and N S the middle vertical wire. It must be observed that the wires are so extremely fine that even when they are magnified by the eye-glass of the telescope they still appear like mere hairs. The number of vertical wires being always odd, one of them will necessarily pass through the centre. The instrument represented in fig. 1 is provided with such adjustments, that the middle wire N S, can be brought to coincide with the utmost precision with the meridian.

The magnifying power of the telescope has the same effect upon the apparent motions of objects as upon their apparent magnitude. It increases the one in the same proportion as the other. The consequence is that, although the apparent diurnal motion of celestial objects is no more perceptible to the naked eye than is the motion of the hour-hand of a watch, yet when viewed with the telescope, this motion is very distinctly perceptible. The stars seem like so many luminous insects, creeping with a visible motion across the field in horizontal directions, and passing in succession behind each of the parallel vertical wires.

27. So rapid is this apparent motion of the celestial objects across the field of the telescope, that a star is seen to pass from one side to the other of one of the vertical wires between two successive beats of the clock. Thus it may be seen at *o*, fig. 2, at the moment marked by one beat, and at *o′*, at the moment marked by the next. Practised observers are in such case able to determine to the tenth of a second, or even less, the instant of its transit over the wire. Thus if the moment it is at *o*, be $10^h\ 20^m\ 20^s$, and that at which it is at *o′*, be $10^h\ 20^m\ 21^s$, the observer will be able to say for example that the instant at which it has passed the wire N S is more than $10^h\ 20^m\ 21^s{\cdot}4$, and less than $10^h\ 20^m\ 21^s{\cdot}5$, and he may assign the time as $10^h\ 20^m\ 21^s{\cdot}45$. Different observers acquire, according to their respective aptitudes, different degrees of skill in such observations, and in all cases the results of their observations can be checked by comparing those obtained

by two or more observers observing the same transit at the same place.

28. If the transit of the same star be observed for two or more successive nights, the interval which elapses between any two successive transits can thus be determined. Now it has been found that this interval is absolutely the same, not only for all stars whatever, but also that it is the same at whatever part of the earth the observation may be made. By comparing the results of ancient with modern observations, it has also been found that this interval has not undergone the least change.

It is well known that this apparent diurnal rotation of the heavens, by which a common motion is thus imparted to all celestial objects, is the optical effect produced by the rotation of the earth upon its axis, and the time of that rotation is consequently the interval which elapses between two successive meridional transits of any fixed star.

Such is the constant and invariable character of this motion, and its absolute uniformity, that Laplace has shown, independently of all theory, that, as a matter of fact, the time of this apparent rotation of the heavens cannot have suffered any change amounting to so much as the hundredth part of a second since the time of Hipparchus, being an interval of twenty centuries.

This interval is called a SIDEREAL DAY.

The sidereal day is subdivided into hours, minutes, and seconds, in the manner already explained.

The circumference of the celestial sphere being supposed to be divided into 360°, through which it revolves in 24 hours, it follows that it turns through 15° per hour, 15′ per minute, and 15″ per second.

It is perhaps to be regretted that the terms minutes and seconds have been used in two different senses, the more especially, as their application in both these senses is constantly necessary in all astronomical works. As applied to the arcs of circles, or to angular measurement, a MINUTE signifies the sixtieth part of a degree, and a SECOND the sixtieth part of a minute. As applied to time a MINUTE signifies the sixtieth part of an hour, and a SECOND the sixtieth part of a minute.

The confusion which might arise in calculations in which both time and angular measures are involved, is prevented by the adoption of the letters ^{m} and ^{s}, to express minutes and seconds of time, and the signs ′ and ″ to express angular minutes and seconds. Thus—

$$8^{h}\ 30^{m}\ 25{\cdot}6^{s}$$

expresses an interval of time consisting of 8 hours, 30 minutes, 25 seconds, and 6-tenths of a second; while

$$8^{\circ}\ 30'\ 25{\cdot}6''$$

expresses an angle or circular arc, the magnitude of which is 8 degrees, 30 minutes, 25 seconds, and 6-tenths of a second.

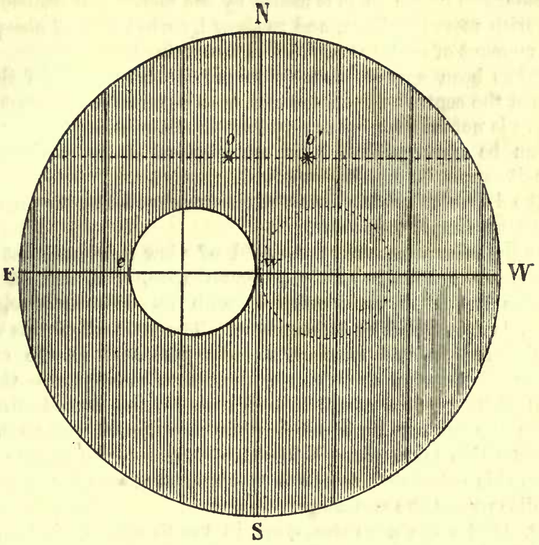
29. The absolute uniformity and permanency which thus characterise the diurnal rotation of the heavens, combined with the fact that it is observable at all parts of the earth, would render it eminently suitable as a measure of time. It wants, nevertheless, one condition which is quite as essential for the purposes of civil life as uniformity and permanence. It is not marked and limited by any conspicuous phenomena which strike the senses of all mankind. It does not correspond with the periodical returns of light and darkness, nor with the successive returns of the sun to the meridian. It does not even fall into accordance with the conspicuous lunar phenomena; so that, although it be true that it is observable alike in all parts of the earth, the phenomena by which it is marked are such as can only be observed with the aid of astronomical instruments, and such as do not address themselves to mankind in general.

30. To obtain, therefore, a fit measure of time for civil purposes, some measure must be found which will fall into such accordance with the periodical vicissitudes of light and darkness and the successive meridional transits of the sun, that the chronometric unit may correspond either exactly, or nearly enough, for all practical purposes with those diurnal appearances by which the records of mankind have in all ages and countries been made.

And why, it may naturally enough be asked, may not the successive returns of the sun to the meridian serve the purpose?

It may be stated briefly but distinctly that the solar diurnal phenomena, as they are actually presented in the heavens, do not answer as a measure of time even for civil, to say nothing of scientific purposes. Why they are unsuitable, and what substitute has been contrived for them, will require some words of explanation.

Fig. 2.



COMMON THINGS.

TIME.

CHAPTER II.

31. How to observe the sun's transits.—32. Interval between them variable.—33. Mean and apparent time.—34. Relative changes of mean and apparent time.—35. The days on which they coincide.—36. The Equation of time.—37. Further explained.—38. Its extreme error.—39. Mean time adopted in France.—40. Unfitness of apparent time.—41. Local time varies with longitude.—42. Equalisation of local time proposed.—43. How timepieces are regulated.—44. Mean solar hours, minutes, and seconds.—45. Length of sidereal day.—46. The week.—47. Opinions as to its origin.—48. Both opinions erroneous.—49. Origin of the names of the days.—50. First day of the week.—51. The month.

31. The sun presenting to an observer not merely a brilliant point, as is the case with a fixed star, but a circular luminous space called a disc, of considerable magnitude, the various parts of which pass the meridian at different moments of time, it is

necessary to define what is meant by the meridional transit of the sun with more precision, and to show by what sort of observation the moment of such transit can be ascertained.

It has been agreed, that by the meridional transit of the sun, that of the centre of the solar disc is to be understood. But as this centre is not marked by any visible or observable point by which it can be distinguished from other points of the sun's disc, its transit cannot be directly observed.

The difficulty arising from this circumstance has been overcome by a very simple expedient.

As the solar disc enters the field of view from the east side it approaches gradually the meridional wire, N S, and at length touches it, as shown in fig. 2, with its western edge, W, or LIMB, as it is called by astronomers. The moment of this contact is observed in the manner already described in the case of a star. The solar disc then continues to move across the field until it takes the position indicated by the dotted circle, in which the eastern limb touches the meridional wire, N S. The moment this takes place being also observed, the middle of the interval is calculated, which is the instant at which the centre of the disc passed the meridian.*

32. If the sun were stationary in the firmament, it is evident that the interval between its successive meridional transits would be the same as that of the successive transits of a fixed star, and in that case the SIDEREAL DAY would be identical with the SOLAR DAY. But it is well known that the sun is not thus fixed. On the contrary, it moves constantly in the firmament, making a complete circuit of the heavens in a year. If this motion were uniform, the daily displacement of the sun would be 0° 59′ 8·2″.

Now let us consider what effect such a displacement, being always eastward, would produce upon the interval between the successive transits of the sun compared with that of the transits of a star which suffers no such displacement.

Let *s* (fig. 3) represent the sun at the moment its centre is on the meridian, N S, on any given day, and let *o* represent a fixed star which is on the meridian at the same instant. After the lapse of 24 sidereal hours the star, *o*, will be again upon the meridian, N S; but during these 24 hours the sun, *s*, will have moved towards E, that is, eastward to the position, *s′*, the distance, *s s′*, being

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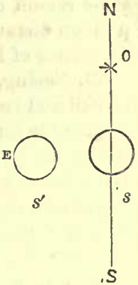
* In fig. 2 the motion of the celestial objects and their position is represented as they are seen by the naked eye, or by a terrestrial telescope. But all objects are inverted and reversed by the astronomical telescope, so that the top is seen at the bottom, and the east seen at the west, and *vice versâ*. It has been thought better for the present purpose to represent the points and motions as they are naturally seen.

0° 59′ 8·2″. The sun, therefore, will not yet have come to the meridian, and will not arrive at it until it is carried by the diurnal motion of the firmament through this space of 0° 59′ 8·2″. But since the firmament moves at the rate of 15′ in each minute of time, it will take 3^{m} 56^{s} to carry the sun, *s′* to the meridian. It follows, therefore, that, supposing the sun to move daily 0° 59′ 8·2″ eastward at right angles to the meridian, a solar day would exceed a sidereal day by 3^{m} 56^{s}.

Fig. 3.



If the eastward daily motion of the sun, measured at right angles to the meridian, were uniform therefore, the interval between its successive transits would possess all the requisites for a chronometric unit, and although the solar day would not be equal in length to the sidereal day, it would, nevertheless, be of invariable length, and would besides be in complete accordance with those periodical vicissitudes of light and darkness which have been, by common consent, used by mankind in all countries and in all ages as the measures of time.

But the solar day is wanting in fact in this essential condition; it is not invariable in length. Its variation, though not great, is nevertheless such as to render it unsuitable as an unit of time, even for civil, to say nothing of astronomical, uses. No clock or watch could be constructed which would continue to go with the sun. A clock, which at one time of year would correspond with the meridional transits, would at another either anticipate them, or fall behind them.

The variation in the rate at which the sun is displaced daily towards the east, and at right angles to the meridian, arises from several causes. *First*, the rate at which the sun moves upon the firmament is subject to variation. While its average daily displacement is, as we have stated, 0° 59′ 8·2″, it amounts at the beginning of the year to 1° 1′ 9·9″, and at the middle of the year to only 0° 57′ 11·5″. Although we are not directly concerned here with the cause of this variation, it may be as well to observe, that it arises from the fact that the earth does not revolve in an exact circle with the sun in the centre, which it must have done if its motion were uniform, but in an oval, the sun being nearer to one end than to the other, and the rate of the motion increasing as the distance of the sun decreases. *Secondly*, the motion of the sun is not generally at right angles to the meridian, but more or less oblique to it at different seasons, and the more oblique it is to the meridian, the less does a given displacement affect its eastward motion at right angles to the meridian. *Thirdly*, the sun is at different seasons at different distances from the celestial equator, and the more remote it is from the equator the more does a given displacement affect its return to the meridian, for the same reason exactly as that for which two places on the earth, at a given distance east and west of each other, will have a greater difference of longitude the farther they are from the line.

33. Seeing, then, that the interval between the successive meridional transits of the sun is subject to variation, and therefore unsuitable for a chronometric unit, but that it would be suitable if the sun's daily easterly displacement were always the same, astronomers have imagined an expedient, which, without sacrificing the advantage of an accordance with the periodical vicissitudes of light and darkness, secures the advantage of complete uniformity as to the length of the chronometric unit.

This is accomplished by the substitution for the real of a fictitious sun, whose daily easterly motion is always the same, and exactly equal to the average daily easterly motion of the real sun, that is, to 0° 59′ 8·2″. The time, as indicated by this fictitious sun, is called MEAN TIME, the moment when its centre passes the meridian is called MEAN NOON, and the fictitious sun itself is sometimes called the MEAN SUN.

The variable and unavailable time indicated by the motion of the real sun is called APPARENT TIME, and the moment of the meridional transit of the real sun is called APPARENT NOON.

34. From what has been stated, it will therefore be understood that the mean and the real suns make a complete circuit of the heavens in exactly the same time, that is, in a year; so that, starting together from a given point, they will arrive together at the same point at the instant which terminates the year; but while the easterly daily displacement of the one is always absolutely the same, being 0° 59′ 8·2″, that of the other is variable, being sometimes greater than 0° 59′ 8·2″, sometimes less, and at certain times the same.

To illustrate the changes of the relative position of the two suns, let us imagine two railway trains to start from London at the same moment, side by side, on two lines of rails, making a trip to Liverpool and back, and to arrive at London, on their return, precisely at the same moment; but let the speed of one be absolutely uniform, at 30 miles an hour, during the entire journey, while that of the other is subject to variation, being slower in ascending inclines, and faster in descending them. The latter will at some places outstrip, and at others fall behind, the former, and at certain points they will be for a moment side by side. The variable train will represent the real, and the uniform train the fictitious or mean sun.

The two trains throughout their trip would, in such case, never be found very far asunder. Neither will the two suns separate to any great distance. If they did so, the expedient of the fictitious sun as a measure of time for civil purposes would fail, inasmuch as the civil day would fall into perceivable disaccord with the real day.

35. The days of the year at which the true and fictitious suns come together, and on which the mean and apparent time agree, are subject to a very slight variation; but in the year 1855, this coincidence takes place on the 15th April, 15th June, 1st September, and 24th December.

To trace the relative positions of the mean and real suns, we are to consider that on the 15th April they are on the meridian together, or very nearly so. The next day the mean sun will have passed to the east of the real sun, so that the latter will arrive at the meridian first, and when the mean sun comes upon the meridian, that is, at the moment of mean noon, the real sun will be to the west of it. Each succeeding day the real sun will fall back more and more to the west of the mean sun, and the apparent noon will precede the mean noon by a constantly increasing interval. Thus, on the 16th April, the apparent precedes the mean noon by 8^s, on the 17th by $22{\cdot}4^s$, on the 18th by $36{\cdot}4^s$, on the 19th by 50^s, and so on; this gradual increase going on until the 15th May, on which day the apparent precedes the mean noon by $3^m\ 53{\cdot}87^s$, and the distance of the true sun, west of the mean sun, is then $58'\ 28''$, a space equal to nearly twice the apparent diameter of the sun.

After the 15th May the real sun falls less and less west of the mean sun, so that the two suns approach each other closer and closer until the 15th June, when they again coincide. Thus, from the 15th April to the 15th June, the apparent time precedes the mean time by a quantity which varies from 0 to $3^m\ 53{\cdot}87^s$, and the distance of the real sun to the west of the mean sun varies from $0°$ to $58'\ 28''$.

As the time shown by the mean sun is the time shown by a properly regulated clock, it follows that during this interval the sun passes the meridian before noon—a fact which is commonly expressed by saying that the sun is FAST.

36. The interval of time between the meridional transits of the real and fictitious suns, or what is the same, the interval between the apparent noon and the mean or civil noon, or the noon shown by a properly regulated clock, is called the EQUATION OF TIME.

37. Between the 15th April and the 15th June it appears, therefore, from what has been explained, that the time of mean noon can be deduced from that of apparent noon by subtracting

from the latter the equation of time, and on the other hand, the time of apparent noon is deduced from that of mean noon by adding to the latter the equation of time.

But to trace further the relative positions of the true and mean suns. After the 15th June the real sun falls to the east of the mean sun, and consequently does not come to the meridian until after the mean sun has passed it, that is, until after noon. On the 16th June the real sun passes the meridian 13·53ˢ later than the mean sun; on the 17th, 26·43ˢ; on the 18th, 39·42ˢ; on the 19th, 52·44ˢ; and so on, passing it each day later and later in the afternoon, until the 26th July, when it passes the meridian 6ᵐ 12·68ˢ later. After that day it begins to pass the meridian at earlier intervals after the mean sun, and the intervals become less and less until the 1st September, when it coincides with the mean sun.

On the 26th July the apparent noon being 6ᵐ 12·68ˢ later than mean noon, the centre of the real sun must be 1° 33′ 10·2″ east of the centre of the mean sun, which is a space equal to about three times the apparent diameter of the sun.

Thus it appears, that from the 15th June to the 1st September, the apparent time follows the mean or civil time, that is to say, the sun passes the meridian at times varying from 0 to 0ʰ 6ᵐ 12·68ˢ in the afternoon. This fact is usually stated by saying that the sun is SLOW.

During this interval the apparent time is found by subtracting the equation of time from the mean time, and the mean time by adding it to the apparent time.

After the 1st September the real sun again passes to the west of the mean sun, and consequently passes the meridian before it.

Thus, on the 2nd September, its meridional transit takes place at 19·68ˢ before noon; on the 3rd at 38·77ˢ; on the 4th at 58·11ˢ; and so on, the transit being earlier and earlier until the 3rd November, when it takes place at 16ᵐ 18·51ˢ before noon, which is therefore the greatest amount of the equation of time, and the greatest departure of the time of the sun from the time of the clock. The sun is in this case 16ᵐ 18·51ˢ fast.

38. Since the firmament moves at the rate of fifteen minutes of arc for every minute of time, it follows that in 16ᵐ 18·51ˢ before the meridional transit of the sun, its departure from the meridian must amount to 4° 4′ 37·65″, a space equal to nearly eight times the sun's apparent diameter.

From the 3rd November to the 25th December the distance of the real sun west of the mean sun constantly decreases, and they coincide on the 25th December.

It follows, therefore, that from 1st September to the 25th

December, the sun is fast by an interval which varies from 0 to $16^{m}\ 18{\cdot}51^{s}$.

After 25th December the real sun once more falls to the eastward of the mean sun, and consequently it does not arrive at the meridian until after the mean sun has passed it, that is until some time after the mean noon. On the 26th December it passes the meridian at $40{\cdot}45^{s}$; on the 27th at $1^{m}\ 10{\cdot}15^{s}$; on the 28th at $1^{m}\ 39{\cdot}71^{s}$ after noon, and so on, the lateness of its transit increasing until the 11th February, 1856, when it passes the meridian at $14^{m}\ 32{\cdot}36^{s}$ after noon. After this its transit is less and less late until the 15th April, when it again coincides with the mean sun.

It appears, therefore, that from the 25th December to the 15th April the sun is always slow, its deviation from the time of the clock being greatest on the 11th February, when it amounts to $14^{m}\ 32{\cdot}36^{s}$. The distance of the true sun from the mean corresponding to this interval, computed as before, is $3^{\circ}\ 38'\ 5{\cdot}4''$. On the 11th February, therefore, the true sun is at this distance east of the mean sun. This distance is not quite seven times the diameter of the sun's disc.

39. The real interval between two successive transits of the sun being variable, it is evident that no piece of mechanism could be constructed which, without adjustment, would point daily to 12 o'clock at the moment of apparent noon. So long, therefore, as the mean time was not adopted as the chronometric measure for civil purposes, it was necessary daily, or at least weekly, to regulate all the clocks, public and private, according to the varying time of apparent noon. This was the practice even in a country so enlightened as France until an epoch so recent as 1816. Before this time the most remarkable disagreement constantly prevailed among the public clocks of Paris, few of which were regulated sufficiently often by observations of the sun. M. Arago relates, that Delambre, the celebrated French astronomer, told him that he frequently heard the public clocks, one after another, striking the same hour during half an hour.

At the time of introducing the change in the regulation of the clocks of Paris from apparent to mean time, the prefect of the Seine (which is the title of the chief of the municipality, or mayor of Paris,) entertained such serious fears that an insurrectional movement might be excited among the working classes, who, it was supposed, would revolt against a noon which did not correspond with the noon of the sun, or mid-day, and which consequently would divide the day, from sunrise to sunset, into two unequal parts, that he refused to sign the *ordonnance* for the change unless it was accompanied by a formal report of the Board of Longitude to sanction it. These apprehensions, however, proved groundless, for the change took place unperceived by the great mass of the people.

Meanwhile the watch and clockmakers rejoiced at the change which established a sort of civil time, in accordance with which it was mechanically possible to construct timepieces. Such a change relieved them from the annoyance produced by the remonstrances of their customers complaining of their best constructed watches losing or gaining as much as a quarter of an hour, or even more, upon the sun. It was in vain that the celebrated Breguet, and his colleagues of the trade, assured them that the sun and not the watch was too fast or too slow.

40. It may be easily imagined how utterly incompatible with the management of public business as now conducted such an imperfect system of chronometric regulation would be, when it is considered what disastrous consequences might arise upon railways, if the starting, stopping, and arrival of trains, were not subject to greater precision than could be attained under such circumstances.

41. However exactly the chronometric measures in a given place may be regulated, their indications will necessarily differ from those of similar chronometric measures in other places having different longitudes. The cause of this difference is the successive arrival of the mean sun at the several meridians of such places. By the apparent diurnal motion of the heavens, the sun, carried round the globe, arrives in succession, from hour to hour, at the meridians of places situate one westward of the other, and as the sun thus carried round makes a complete revolution in 24 hours, it moves from meridian to meridian at the rate of 360° in 24 hours, or 15° per hour, or 1° in four minutes. Thus, at two places differing in their longitude by 1°, the local time will differ by four minutes, that which is east being four minutes earlier than that which is west.

In consequence of this the clocks in different towns of the United Kingdom show at the same moment of absolute time different hours. Liverpool, for example, being 3° west of London, and 1° being equivalent to four minutes, it follows that the sun passes the meridian of London twelve minutes before it passes that of Liverpool; and as this is equally true of the fictitious sun which regulates civil time, it follows that mean noon at London, and therefore all other hours determined with relation to mean noon, precede the corresponding hours at Liverpool by twelve minutes.

42. It has been lately proposed to assimilate the chronometric epochs at all parts of the United Kingdom, by means of clocks which are moved with a common motion, so that their hands,

however distant they may be one from another, must always point at the same moment to the same hour. Such a common motion may be imparted to them by means of an electric current transmitted along conducting wires, similar to those used for the electric telegraph. In this way all clocks in all parts of the kingdom could be made to indicate the Greenwich time.

If this measure should be adopted the civil time will have undergone another change, and instead of being the mean time proper to the place, it will be the mean time at Greenwich. Thus the civil time at Liverpool, for example, would differ from the mean time there by twelve minutes. And as the mean time at certain epochs already differs from the apparent time by more than a quarter of an hour, it will sometimes happen that the civil time will differ from the apparent time by nearly half an hour. Thus the sun may be on the meridian of Liverpool, and consequently the real mid-day may take place at about half-past eleven o'clock.

Such a circumstance, however contradictory and anomalous it may appear when considered astronomically, would, however, be attended with no inconvenience in civil life.

43. The length of a mean solar or civil day, and the method of defining the moment of its commencement, being well understood, it remains to show how the motion of a timepiece is regulated so as to represent it.

Let us suppose a clock, the pendulum of which is intended to beat seconds, to be roughly regulated, so that its hour-hand shall make two complete revolutions in a day. This approximation to an exact movement may be easily accomplished by many obvious expedients, one of which would be to set it to twelve o'clock when the sun appears to have attained its greatest altitude.

The clock, thus approximately regulated, being placed near a transit instrument, such as that already described (26), let the observer, as the sun approaches the meridian, direct the telescope to the point of the meridian over which it is about to pass. When the disc of the sun enters the field of view, and is approaching the wire, N S, fig. 2, let the observer look at the clock, and observe the exact time, and let him count the time from that moment by his ear as he listens to the successive beats of the clock. Continuing thus to count, he will find that the western edge of the sun's disc will touch the wire N S at a certain moment between two successive beats, and by practice he will be able to assign the moment of contact between the beats. As the disc of the sun takes about two minutes to pass across the wire, he will have sufficient time to write down the exact time of the transit of the western edge and to return to the telescope before the eastern edge comes near the wire. Again observing the time shown by the clock, and again counting the beats he observes, in like manner, the moment at which the eastern edge touches the wire.

Now let us suppose the times of contact to be as follows:—

	H.	M.	S.
Contact of Western limb . . .	12	10	$8\frac{3}{10}$
Contact of Eastern limb	12	11	$59\frac{5}{10}$
	24	22	$7\frac{8}{10}$
Transit of sun's centre . .	12	11	$3\frac{9}{10}$

As has been already explained, the time of the transit of the centre of the sun's disc is found by adding together the times of the transits of the eastern and western limbs, and dividing the sum by two.

It would then appear from this that the time shown by the clock at the moment of apparent noon is eleven minutes and three seconds, and nine-tenths of a second after twelve.

Let us suppose that the observer then refers to the table of the equation of time for the day of the observation, and finds there that the moment of mean noon was $3^{m}\ 32\frac{1}{10}{}^{s}$ earlier than the apparent noon. To find the time of mean noon, therefore, as shown by the clock, he performs the following arithmetical operation:—

	H.	M.	S.
From apparent noon	12	11	$3\frac{9}{10}$
Subtract the equation of time . .		3	$32\frac{1}{10}$
	12	7	$31\frac{8}{10}$

From which it appears that the clock is $7^{m}\ 31\frac{8}{10}{}^{s}$ fast.

Leaving the clock unaltered, the same observations and calculations are made the following or any succeeding day, and if the clock gives a later hour than $12^{h}\ 7^{m}\ 31\frac{8}{10}{}^{s}$ for mean noon, its rate is too fast, or it "gains." If it gives an earlier hour, its rate is too slow, or it "loses." Let us suppose, for example, that after the lapse of five days the clock gives $12^{h}\ 8^{m}\ 25\frac{3}{10}{}^{s}$ for mean noon, we shall have

	H.	M.	S.
Mean noon—sixth day	12	8	$25\frac{3}{10}$
,, first day	12	7	$31\frac{8}{10}$
Clock gains in five days	0	0	$53\frac{5}{10}$

The clock therefore gains at the rate of $10\frac{7}{10}$ seconds per day.

The method of correcting the rate is by lengthening the pendulum, as will be explained in a future number of the MUSEUM.

44. When the pendulum has been exactly regulated, it will swing 86400 times between the moments of mean noon on two successive days. The time of 60 swings will be a mean solar minute, and the time of 3600 will be a mean solar hour. The clock thus regulated, being set to 12 at the moment of mean noon, will again point to 12 at mean midnight, and again at the succeeding mean noon, and so on.

45. From what has been explained, it will be understood that a sidereal day, or the time of the rotation of the earth upon its axis, is somewhat shorter than a common civil day. The exact proportion between these chronometric units, which is by no means an easy problem, has, however, been solved by astronomers, and it is found that 100,000000 common or civil days are equal to 100,273791 sidereal days, or, if less extreme arithmetical precision be sufficient, it may be stated that in a thousand common days the earth makes $1002\frac{3}{4}$ rotations on its axis.

From these numbers it is easy to express the time of rotation in hours, minutes, and seconds of civil time. To do this we have the proportion

100,273791 : 100,000000 : : 24 : the time of rotation.

By the rule of three, therefore, the time of rotation will be

$$\frac{\overset{\text{hours.}}{2400,000000}}{100,273791} = 23^{\text{h}}\ 56^{\text{m}}\ 4{\cdot}09^{\text{s}}.$$

It appears, therefore, that the time of the earth's rotation falls short of 24 hours, such as those shown by well regulated clocks, by three minutes, fifty-five seconds, and ninety-one hundredths of a second.

IV.—THE WEEK.

46. Having thus explained fully the meaning of a day, considered as the standard unit of time, and of the subordinate and lesser divisions of hours, minutes, and seconds, it will now be necessary to notice the larger chronometric units.

The chronometric unit, in the ascending order, which comes next to the day, is the WEEK.*

47. The opinions of historians and antiquarians are much divided as to the date and prevalence of the custom of counting time by periods of seven days. It is certain, however, that among the oriental nations such a period has been in use from time immemorial. Philo Judæus, Josephus, and St. Clement of

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* From the Saxon word WEOC, having the same signification.

Alexandria, maintained that the period of a week was in use among all ancient peoples. Goguet, a modern French authority, adopts the same opinion. Others, on the contrary, among whom may be mentioned Costard and Maury,* contend that no ancient use of the period of seven days prevailed except among the Jews, who took it of course from the traditions of the creation, given in the Pentateuch.

48. Both these extreme opinions, but especially the latter, are erroneous. The week, as a division of time and multiple of a day, was in general use among the ancient Chinese, the Egyptians, the Chaldeans, and the Arabs, as well as among the Jews. It was not in the calendar of the Greeks, who divided the month into three periods of ten days, and it was not adopted by the Romans until the time of Theodosius, who reigned in the latter part of the fourth century of our era. There is properly no word in the Latin classics equivalent to the term WEEK. *Hebdomas* signified seven of anything, and when applied to days had reference to diseases, in which the physicians held (as now appears erroneously) that crises were manifested of which the periods were 7, 14, and 21 days.

While most authorities trace the use of weeks to the Mosaic account of the creation, others ascribe it to the phases of the moon, and others again to the planets as known to the ancients. The lunar phases not being even nearly commensurate with the week, they can scarcely be regarded as the origin of this chronometric unit, and the denomination of the days having in all languages more or less reference to the celestial objects, the latter opinion seems to be most generally entertained.

49. In the ancient Egyptian astronomy, the sun and moon being included among the planets, and of the bodies properly called planets, five only being known, Mercury, Venus, Mars, Jupiter, and Saturn, the total number of planets was taken to be seven. They were ranked in the order of their supposed distances from the earth as follows:—

1. SATURN
2. JUPITER
3. MARS
4. THE SUN
5. VENUS
6. MERCURY
7. THE MOON.

Dion Cassius, an eminent historical writer of Rome, who was consul about 220 A.D., gives the following explanation of the manner in which the Egyptians derived the names of the days of the week, and their order, from those of the seven planets.

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* See dissertation by M. Biot upon the astronomical chronology.—Mem. Acad. Sc. tome xxii.

THE WEEK.

The series of hours without reference to days were resolved into periods of seven, each dedicated to a planet. Thus the first hour was dedicated to Saturn, the next to Jupiter, the third to Mars, and so on. The day, however, being divided into twenty-four hours, which is not a multiple of seven, it followed necessarily that each successive day would begin with an hour dedicated to a different planet. Let us see then how the days would, according to such a system, succeed each other.

The day which begins with the hour dedicated to Saturn would evidently end with the hour dedicated to Mars, for the twenty-four hours would consist of three complete periods of seven, and the twenty-fourth hour would be the third of the fourth period and would consequently be the hour dedicated to Mars. The first hour of the next day would be that dedicated to the Sun. In like manner this day beginning with the hour dedicated to the Sun, and consisting of three hours more than three complete periods, would end with the hour dedicated to Mercury, and the next day would begin with the hour dedicated to the Moon.

The succeeding day would in like manner commence with the third in order from the Moon, that is, Mars; the next with the third in order from Mars, that is Mercury; the next with the third in order from Mercury, that is Jupiter; the next with the third in order from Jupiter, that is Venus; and after Venus the series would recommence with the hour dedicated to Saturn.

Thus in each successive period of seven days, the first hour of each successive day of the period would be dedicated to the planets in the following order:—

1. Saturn
2. The Sun
3. The Moon
4. Mars
5. Mercury
6. Jupiter
7. Venus.

The Latin names of the days are in accordance with this,

1. Dies Saturni (Saturn's day)
2. Dies Solis (Sun's day)
3. Dies Lunae (Moon's day)
4. Dies Martis (Mars' day)
5. Dies Mercurii (Mercury's day)
6. Dies Jovis (Jupiter's day)
7. Dies Veneris (Venus' day).

These names are retained in the English language for Saturday, Sunday, Monday. The names for the days dedicated to Mars, Mercury, Jupiter, and Venus have been taken from Saxon divinities.

The days of Mars, Jupiter, and Venus have been called TUESDAY, THURSDAY, and FRIDAY, from TUESCO, THOR, and FRIGGA, the Mars, Jupiter, and Venus of the Scandinavian mythology. The day of Mercury has been called WEDNESDAY, from WODIN or ODIN, the chief of the gods.

In all legislative and judiciary acts and documents, the Latin names of the days of the week are still retained.

Derivations of the Latin names, with one or two exceptions, are used in the languages of Western Europe. SUNDAY is an exception, the name of which is a derivative of DIES DOMINICA, the LORD'S-DAY, and SATURDAY, in Italian, is SABBATO, the SABBATH, that day being the Jewish Sabbath.

There is another method of connecting the series of days of the week with the seven celestial objects from which their names have been taken, so as to explain the order in which they succeed each other, which if it be only from respect to its antiquity may be worth mentioning here.

The ancient astrologers, among whom were included a large number of astronomers, properly so called, imagined a mystical figure, in the centre of which the earth was placed, surrounded by the seven celestial bodies dividing the circular space as shown in fig. 4, into seven equal arcs. From each planet's place two straight lines were supposed to be drawn to the places of the two most remote planets in the circular order, so as to form seven triangles, each of which has two rectilinear sides and an arc of the circle as its base. The planets succeed each other round this circle in the order of their then supposed distances, in the same manner as already explained. Thus Saturn is succeeded by Jupiter, which is followed by Mars, and so on as in the former case.

Now let us suppose that commencing from any one planet, the moon for example, we follow in regular succession the intersecting straight lines, we shall find that the planets succeed each other in the same order as that of the days of the week, or in the contrary order. Thus proceeding from A, we pass to B, from B to C, and so on, following the course indicated by the arrows, and the names of the planets at A, B, C, D, E, F, and G are precisely those from which the names of the days of the week, beginning from Monday and ending with Sunday, are taken. If we had followed the other course against the direction of the arrows, we should have obtained the names in a contrary order, as if we went backwards through the week.

In the cabalistic doctrines of astrology there were various influences imputed to the succession of planets thus obtained, with which we have however here no concern.

In both systems the number seven which forms the basis of the chronometric period of a week had its origin in the supposed number of the planetary bodies. This number seven was in other respects regarded by the ancients as being invested with various mystical influences, and as being reproduced in forms infinitely various, not only in the natural objects and phenomena, but even in human events. There were the seven stars, the seven cardinal sins, the seven wonders of the world, the seven critical days in human maladies, the thrice seven years which converted a youth into a man, and so on. In short the number seven was regarded with a sort of religious veneration, so that the announcement of an eighth or ninth planet in Egypt, Greece, or Rome would, as Arago wittily observed, have been regarded as such a heresy as to bring upon the unhappy discoverer the maledictions of the priests and even the punishment of death instead of the honours and rewards of academies and universities.

50. The week being an arbitrary and conventional chronometric period, having no relation to any natural phenomenon, the day which begins it is equally so. In the Hebrew Scriptures its origin being connected with the narrative of the creation, and the institution of the Sabbath being a perpetual commemoration of the succession of divine acts by which the present state of the earth and the creatures which inhabit it were called into being, the seventh, or last day of the week, would naturally be that upon which the Sabbath is celebrated, and according to this principle Sunday would be the last and Monday the first day of the week. Such, however, has not been the conventional arrangement. The Sabbath, or seventh-day of the Jews, was the morrow of the Crucifixion, and was Saturday; the succeeding day being that of the Resurrection, was consequently the first day of the Jewish week.

Among Christians, this first day has accordingly been celebrated as Sunday, or the day of rest and prayer, the Jews still of course observing Saturday as their Sabbath.

It has therefore been generally agreed to call Sunday the first day of the week, but to invest it with those sacred attributes and characters which in the fourth commandment were conferred upon the seventh day.

V.—THE MONTH.

51. The next chronometric unit is the month, a name which implies some correspondence with lunar phenomena. The relation of this division of time to the moon is apparent in all languages. Thus, while in Greek μην (mēn) is *month*, μήνη (mēnē) is *moon*, both being derived from the Sanscrit MÂ, *measure*, the Persian MÂH signifying also *month*.

The sun and moon move round the celestial sphere in the same direction from west to east, but the moon moves more than thirteen times faster than the sun, and consequently makes more than thirteen revolutions of the heavens while the sun makes one. The moon is therefore constantly either departing from or approaching to and overtaking the sun. At the moment it overtakes the sun it is said to be in CONJUNCTION, and is called NEW MOON. At the moment it is in the opposite part of the heavens, and when therefore it is 180° removed from the sun, it is in opposition; and as it then presents its enlightened hemisphere directly towards the earth, it appears with a complete circular disc, and is called FULL MOON. When it is a quarter of the heavens, or 90°, before or behind the sun, it is said to be in the QUARTERS, and appears as an enlightened semicircle, and is called HALF MOON.

The time which the moon takes to make one complete revolution of the heavens, is called the moon's "period," or "periodic time," and is found by the most exact modern observations to be

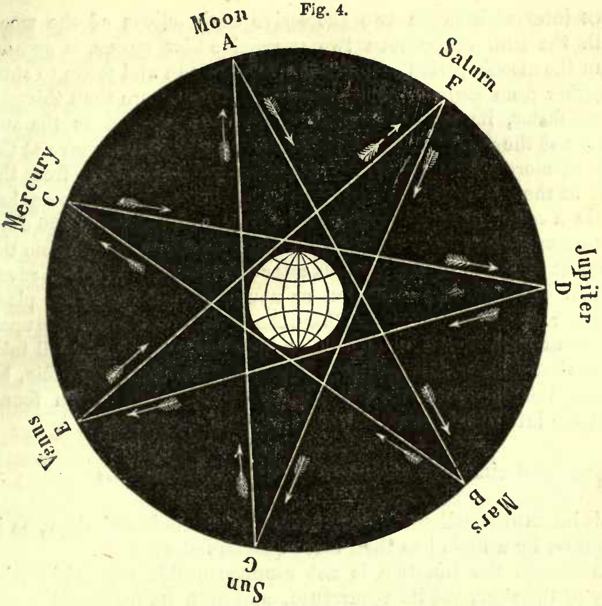
$$27{\cdot}32166 \text{ days}$$

expressed in decimals. If expressed in hours, minutes, and seconds it is

$$27^{d}\ 7^{h}\ 43^{m}\ 11\tfrac{4}{10}^{s}.$$

The moon's period is unsuitable for a measure of civil time for two reasons: first and chiefly because the moment which terminates one period and begins the next, is not marked by any conspicuous and generally observable phenomenon, and can only be ascertained by astronomers; and secondly, because it is incommensurable with the fundamental chronometric standard, the day, and as will hereafter appear, equally so with the year. For these reasons it has never been adopted as a chronometric unit either for civil or astronomical purposes.

Fig. 4.



COMMON THINGS.

TIME.

CHAPTER III.

The month (continued).—52. Not conformable with lunar periods.—53. Difficulty of subdividing the year.—54. Division unequal.—55. Egyptian months.—56. Greek.—57. Solon's months.—58. Roman months. —Romulus.—59. Origin of names of months.—60. Additional months of Numa.—61. Origin of their names.—62. Their lengths.—63. Superstition in favour of odd numbers—methods of remembering the lengths of the months.—64. Calends. — 65. Greek Calends.—66. Nones.—67. Ides.—68. Practice of counting backwards.—69. Discordance of the Roman year with the seasons.—70. Month Mercedonius.—71. Legal meaning of "month."—72. The year.—73. What is a year?—74. Egyptian.—75. Only a rude approximation to the course of the seasons.—76. The vague year and Sothic period.—77. Advantage of Egyptian year.—78. Greek year.—79. Meton and his cycle.—80. Origin of Golden Number.—81. Meton ridiculed by Aristophanes.—82. Near accordance of the lunar phases with the Metonic cycle.—83. Roman year.—84. Pontifical abuses.—85. Julian Calendar. —86. Bissextile years.

The interval between two successive conjunctions of the moon with the sun, or between two successive new moons, is greater than the moon's period. If we suppose the sun and moon to start together from conjunction, the moon moving more than thirteen times faster, immediately goes before the sun; and as the sun moves at the rate of about 1° per day, the moon must move at the rate of more than 13° per day, and consequently departs from the sun at the rate of more than 12° per day. When the moon has made a complete revolution, that is at the end of 27·32166 days from conjunction, the sun will have advanced about 27° from the place at which the moon arrives after having completed its revolution. The next conjunction or new moon cannot take place therefore until the moon overtakes the sun, and as it advances upon the sun at the rate of a little more than 12° per day, it will take somewhat more than two days to come up with it. In fine, by the most exact observations and calculations, it has been found that the interval between two successive conjunctions is

29·530589 days

expressed decimally, or in hours, minutes, and seconds

$$29^{d}\ 12^{h}\ 44^{m}\ 2{\cdot}89^{s}.$$

This interval is called a LUNATION, and it exceeds 29½ days, as it appears, by a little less than three quarters of an hour.

Although the lunation is not commensurable with either the day or the year, yet its recurrence, and even its fractional parts, are marked by phenomena so striking and so universally observable without instruments, that in all ages and all countries it has by common consent been used to measure time, the fractional parts by which it exceeds 29 and falls short of 30 days, being compensated by various expedients.

The evident object to which the adoption of months was directed was to establish a convenient chronometric unit, holding an intermediate place between the week and the year; such unit to consist of a complete number of days without a fraction, and to be at the same time an exact submultiple of the year; that is, such an interval that the year should be an exact multiple of it, and finally that it should be in as near accordance as might be found practicable with the period of the lunar changes.

That various nations in different ages should be found in complete disaccord in their attempts at the satisfaction of these several conditions, and that the usages and chronological forms into which these attempts resolved themselves should exhibit much confusion, will not be at all surprising when it is considered that the conditions themselves are not only incompatible one with another, but their satisfaction utterly impracticable.

These conditions involve the consideration of three distinct chronometric periods, the diurnal, the lunar, and the solar or annual. The lunar period, whatever be the phenomena on which it is based, whether it be the actual time of the revolution of the moon round the earth, or the interval between its phases, that is between full moon and full moon, is neither a multiple of the day nor a submultiple of the year. A month therefore, determined by the lunar period in whatever way it be considered, could not consist of an exact number of days, nor be so taken that the year should consist of an exact number of months.

52. All real conformity therefore between the chronometric periods derived from the sun and moon must very soon have been found to be unattainable, and the problem was therefore limited to the establishment of a convenient subdivision of the year, holding a place between the day and the year, dividing the year into an exact number of equal parts, which should be neither too great nor too small for social convenience.

53. Now let us consider how far these several conditions were attainable.

A year, as will presently appear, consists of 365 days *and a fraction.* In its chronological effects this fraction is attended with many inconveniences of its own, but we shall for the present disembarrass ourselves of it and consider the year as the ancients did, to consist of the round number of 365 days.

This number is somewhat unmanageable when the object is to resolve it into equal parts, each of which shall be a whole number. It is divisible without a remainder by 5 and by 73, but by no other whole number.

It follows from this that the year admits of only two subdivisions fulfilling the prescribed conditions. It may be divided into 73 intervals of 5 days, or into 5 intervals of 73 days.

The former subdivision being less than a week, would be obviously inadmissible. By the latter the year would consist of 5 equal divisions of 73 days.

Would such a division fulfil the conditions? Would it be too great for social convenience?

The most conclusive practical answer to this question may be derived from the concurrent testimony of all nations sufficiently advanced to know that the year consists of 365 days. It must have been evident that a division into 5 equal periods of 73 days could be made. Nevertheless no such division of the year was ever proposed. By this common consent therefore such a subdivision has been tacitly but unequivocally pronounced to be unsuitable to the purposes of mankind.

54. Seeing then that no division of the year into equal periods was practicable, two expedients only were presented; *first,* to

divide the year into a certain number of *equal* parts, with a remainder, and to count that remainder as a supplemental part, just as in arithmetic, when the dividend is not exactly divisible by the divisor, we give the quotient, and name the remainder; or, *secondly*, to resolve the year into some convenient number of *unequal* parts, which would be effected by distributing the days composing the remainder between the equal divisions obtained by the former expedient.

Both of these expedients have accordingly been adopted by different nations in different ages, but the latter has eventually received the general preference, and the year is now, by all the more civilised nations of the world, divided into twelve unequal parts, called, somewhat inappropriately, MONTHS.

55. The Egyptians, adopting the first of the expedients above stated, divided the year into twelve equal months of thirty days. The remaining five days formed a complementary division at the end of the year, and were intercalated before the commencement of the next year.

56. The division of the year into months by the Greeks was not only incongruous and obscure, but no two states of the confederation agreed either in the number, or the lengths, or the names of their months, nor even in the beginning of their year. Generally, however, all agreed in resolving the year into twelve months of unequal lengths. Some states commenced the year at the summer solstice, some at the winter solstice, and some at or near the autumnal equinox. A dozen or more separate states called the months by different names. Some months were designated by specific names, while others were indicated only by their numerical order, counting from the beginning of the year; but as the states did not begin their years from a common epoch, months having the same numerical designation in different states corresponded to different seasons. Thus, the fifth Attic month corresponded with November, the fifth Lacedemonian with February, the fifth Bœotian with May, the fifth Delphic with January, and so on. The enormous confusion which must arise from such discordance between different provinces of a nation, having the same language, and the numerous and perplexing difficulties of interpretation of Greek authors, writing according to such different customs, can be easily imagined.

We forbear to encumber our pages with the eleven series of names of these months, which, being all obsolete, would have no other utility than to aid the interpretation of the Greek authors. Those who desire such information, will find sufficient for their purpose in the "Dictionary of Greek and Roman Antiquities" of Dr. Smith, Art. Calendarium.

57. Notwithstanding the discordancy and obscurity which surround the records and usages of the Greeks, in relation to their calendar, their knowledge of the period of the lunar phases which served as the basis of their chronometric system, attained at an early epoch of their history extraordinary precision. The lunation was estimated at $29\frac{1}{2}$ days, which is within three quarters of an hour of its exact length, and it was assumed as their month. Solon went even so far as to make the month exactly conformable to it. The thirtieth day was divided between two successive months; the first half, from sunrise to sunset, being given to the expiring month, and the other from sunset to sunrise to the new month. The day thus shared between two different months was called ἕνη καὶ νεα, the *old and new* day. This correction, however, was only applied to every other month, the intermediate months being limited to twenty-nine days.

At a later period, when this had fallen into disuse, the same name, ἕνη καὶ νεα, was applied to the last day of the month generally.

58. If any evidence were sought to illustrate the difficulty which has attended the attainment of a degree of perfection in the art of counting and recording time, it would be found in a review of the state of that art among the Greeks and Romans, the two most enlightened and civilised nations of antiquity, to whose labours in literature and the sciences the moderns are so largely indebted.

Nothing that can be imagined can exceed the confusion and absurdity which prevailed in the Roman chronometric conventions before a very late period in the progress of the empire.

Romulus, the founder of Rome, established a year, consisting of ten months, six of which had thirty, and four thirty-one days, making the year 304 days.

Since the names given to these months have, for the most part, come down to modern times, and have been adopted in our own nomenclature, it will be useful here to state them, and notice their origin.

The first four months of the year of Romulus were called, MARS, APRILIS, MAÏA, and JUNIUS, from whence our names MARCH, APRIL, MAY, and JUNE.

59. The first took its name from Mars, the father of Romulus, according to the Roman fable.

The origin of the second is somewhat uncertain, some deriving it from the Latin word *aperire*, to *open*, allusive to the state of vegetation in spring; and others from *Aphrodité*, one of the Greek names of Venus.

The names of May and June were taken obviously enough from Maïa, the mother of Mercury, and Juno, the queen of the gods.*

The names of the other six months, expressing merely their numerical order, were—

Quintilis (the fifth)
Sextilis (the sixth)
September (the seventh)
October (the eighth)
November (the ninth)
December (the tenth).

60. A year of 304 days could not long endure, since it would be soon thrown into discordance with the nature of things. It was, accordingly, no later than the succeeding reign, that of Numa, that two months were added to the year. These were called JANUARY and FEBRUARY.

In the first instance, February stood before January, the former being put at the end, and the latter at the beginning of the year. This order was, however, subsequently reversed, and January remaining the first month of the year, February became the second, March being the third, and so on. This will explain a circumstance, which often excites inquiries in relation to the last four months of the year, which appear to hold an order in the series of months different from that indicated by their names. It must be remembered, that when they received their names March was the first month.

61. JANUARY, the first month of the year, took its name from JANUS, a divinity who held an important place in the Roman religion. Janus presided over the beginning of every thing; he was the guardian deity of gates, and was represented with two faces looking to opposite sides. He was on this account selected to preside over the first month.

FEBRUARY took its name from FEBRUUS, an ancient Italian divinity, whose rites were celebrated during the latter part of that month. This divinity also presided over the dead, whose festival, called FERALIA, was celebrated about the same time.

At a later period, the names of the months QUINTILIS and SEXTILIS were changed to those of JULIUS and AUGUSTUS, to commemorate these Emperors, the former of whom, as we shall see, was signalised by a most important reform of the methods of recording time. These names are continued by us for the months of July and August.

Such was the origin of the present names of the twelve months of the year.

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* Ovid gives a different derivation of the names of May and June—namely, that they are the months of the old (majores) and young (juvenes)

"Tertius a senibus, juvenum de nomine quartus."
Fasti, Book I. line 41.

62. Unequal as were the lengths of the months instituted by Romulus, still greater inequality, irregularity, and confusion, were introduced by his successors. In the Romulian year of ten months, the months of March, May, Quintilis (afterwards July), and October, had each thirty-one days, all the others having thirty. When it was decided to render the year more conformable to the solar phenomena, by increasing its length, it was resolved to add fifty-one days to it; but this being considered too much for one month, and too little for two, one day was taken for each of the six months having thirty days; and the fifty-seven days thus obtained were divided into two months, twenty-nine being given to January, and twenty-eight to February.

The months then stood as follows:—

	Days.		Days.
January	29	July (then Quintilis)	31
February	28	August (then Sextilis)	29
March	31	September	29
April	29	October	31
May	31	November	29
June	29	December	29

The practice of such arithmetical caprices in dealing with matters upon which all chronological and historical records must more or less depend, would seem inexplicable if tradition had not supplied a clue to it. Why, for example, take a day from each of the months of thirty, instead of the obvious expedient of taking the *odd day* from each of those having thirty-one days?

63. It appears that in these times odd numbers were regarded as *lucky* or auspicious, even ones *unlucky* or inauspicious. A point was therefore made to create divisions of time, consisting, as far as possible, of odd numbers of days! Months of twenty-nine and thirty-one days were, therefore, preferable to months of thirty days. Fifty-one days being added to 304, gave a year of 355 days, which, being an odd number, answered very well. But it was impossible to divide an odd number into twelve parts, all of which are odd, since twelve odd numbers added together would make an even number. One of the twelve months was doomed, by the very nature of things, and the laws of number, to consist of an even number of days. This unlucky number was, therefore, as a matter of course, assigned to February, over which the Genius of Death presided, and which was appropriated to the celebration of the Festival of the Dead. Hence it arose that February has the exceptional number of twenty-eight days.

Before we hastily visit with harsh censure this most absurd superstition, let us pause, and look at home, and see if we be ourselves totally exempt from ideas altogether as absurd, if not quite as mischievous. Who has not met with persons professing some claims to education and intellectual position, who object to a dinner party composed of thirteen, and to an odd number of candles being lighted on certain occasions? How many who would consider themselves insulted if they were charged with ignorance, object to start upon a journey, or to commence any serious enterprise on a Friday?

The difficulty of recollecting which months have thirty-one and which only thirty days, has been so generally acknowledged, that various technical aids to the memory have been contrived by which they may be at any moment ascertained.

If the months be reckoned in numerical order from the beginning of the year, the odd months, as far as the seventh, and the even ones afterwards, are those which have thirty-one days. Thus, they are the first, third, fifth, seventh, eighth, tenth, and twelfth, which are January, March, May, July, August, October, and December.

When we close the hand there are four projecting knuckles of the four fingers, with depressions between them. If we give the knuckles and intermediate depressions the names of the successive months, recommencing from the first knuckle, after having once gone over them, we shall find that the months of thirty-one days are those which fall upon the knuckles. Thus, the knuckle of the first finger is January, that of the second March, that of the third May, and that of the fourth July. Recommencing then, that of the first is August, that of the second October, and that of the third December.

Every one is familiar with the lines—

"Thirty days hath November,
April, June, and September;
February hath twenty-eight alone,
And all the rest have thirty-one."

64. The first day of a month was called by the Romans CALENDS, a name which was also applied to the months themselves. Hence it came that a table, showing for the current year the succession of months, and of the days in each month, came to be called a CALENDAR.

65. The name Calends was not used by the Greeks. Hence arose a saying when any thing was indefinitely adjourned, that it was postponed to the "Greek Calends."

66. The seventh days of the four great months, as those consisting of thirty-one days were denominated, and the fifth days of all the lesser months, consisting of twenty-nine days, were called NONES.

67. In like manner, the fifteenth days of all the great months, and the thirteenth of all the lesser months were called IDES.

68. The cause of this difference of position of the ides and nones in the greater and lesser months is to be found in the Roman custom of counting time *backwards*. Thus, in all months, greater or lesser, the ides were the seventeenth days, and the nones the twenty-fifth days, counting backwards from the last day inclusive.

It was not only the nones and ides themselves that were counted backwards, but also the intermediate days. Thus, in a month of thirty-one days, the first six days were called successively as follows:—

1st day	Calends
2nd ,, ...	Sixth before the nones
3rd ,, ...	Fifth ,, ,,
4th ,, ...	Fourth ,, ,,
5th ,, ...	Third ,, ,,
6th ,, ...	The eve of the nones
7th ,, ...	The nones.

In the same manner, the days succeeding the nones were counted backwards from the ides, and those succeeding the ides counted backwards from the calends of the next month.

Although carried to such an extent, the practice of backward reckoning was absurd; the method is, in certain cases, obviously convenient, and is still in general use. When remarkable festival days and anniversaries occur, we all find it convenient to name the preceding day their *eve*, and we even sometimes refer to the second or third day before such or such a remarkable epoch.

69. The periodic returns of the seasons taking place at intervals of about 365 days, could not remain long in accordance with a year of 355 days. This was soon perceived; and of all the inexplicable expedients of which the management of chronometric regulation affords any example, certainly the most curious by far was that by which it was attempted to bring the civil into accordance with the natural year.

Imperfect as the knowledge of astronomy was in these times, the mere observation of the returns of the seasons, such as all agriculturists in the rudest state would have made, was enough to show that 355 days was ten or twelve days less than the period of the seasons; and, therefore, that by continuing to count time by such a year, the seasons would return ten or twelve days later from year to year.

70. Numa, the successor of Romulus, who, as has been already stated, modified the calendar, decided that the civil year should be brought into accordance with the period of the seasons, by introducing into every other year a thirteenth month, called

MERCEDONIUS, consisting alternately of twenty-two and twenty-three days. So far the expedient presented nothing very singular, but the manner in which this supplemental bi-annual month was introduced was most curious. It was decreed that the progress of the month of February in every other year should be suspended at the end of the twenty-third day, and that then the month Mercedonius should commence, and that, when it was completed, the month of February should be continued to its last day! Thus Mercedonius was wedged in between the 23rd and 24th of February. In these alternate years, the day after the 23rd February was the 1st Mercedonius, and the day after the 22nd or 23rd Mercedonius, as the case might be, was the 24th February, and the succeeding days the 25th, 26th, 27th, and 28th of February!!!

71. The term month has been used in different senses, one of which is the interval during which the moon makes a complete revolution round the earth.

Four weeks exceeding this interval by no more than sixteen hours, that period of time has been also called a month. According to Blackstone, this is the legal sense of the term, unless a different meaning be expressly given to it. A lease for twelve months is a lease for forty-eight weeks.*

VI.—THE YEAR.

72. This is the largest of the chronometric units, and is consequently that by which all long periods are expressed.

73. What is a YEAR? To most persons it may seem that such a question is superfluous, forasmuch as every one must very well know what a year is. If we press for an answer, and sift such as are given, the matter will not, however, prove to be so plain and so easy.

Some may reply that it is the interval of time during which the sun makes a complete revolution of the heavens.

Others will say that it is the interval determined by the periodical recurrence of the seasons.

The question would be stripped of part of its difficulty if these two intervals were the same. But they are not. If it be replied that their difference is not great, we may rejoin that the difference, however small it may be, will become great by accumulation, and that when the question relates to centuries it may be such as to throw the two definitions into utter discordance.

In explaining the circumstances attending the diurnal unit, we showed that one essential condition attending it was, that it should be invariable; in other words, that every succeeding day should have exactly the same length. The same condition is indispensable; and for the same, and even stronger, reasons in the case of the annual unit. Yet the natural standard from which that unit is taken, the periodical return of the seasons, like the periodical return of the sun to the meridian, is subject to a certain variation. It is on that account unsuitable for a standard measure of time. This defect, however, is removed by an expedient similar to that by which the mean solar day was substituted for the apparent solar day. A fictitious period is assigned to the return of the seasons, which is a mean between the extreme variations of the actual period which marks their successive returns, and this fictitious period, which is invariable and never differs much from the real period, being sometimes a little more and sometimes a little less, is adopted as the chronological year.

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* Blackstone, ii. chap. 9.

Unfortunately for the facility of chronology, however, neither this nor any other standard measure of time based upon the succession of seasons, consists of an exact round number of days without a fraction; nor has the fractional part remaining over a whole number of days the advantage of amounting by any extent of repetition to a day, or even to any whole number of days.

This circumstance, as will presently appear, has been productive of grave inconvenience in history and chronology.

74. In their first rough attempt at the establishment of the annual standard of time, the Egyptians gave the year 360 days, divided into twelve equal months of 30 days.

This is supposed to have been the origin of the division of the circle into 360 degrees, and indeed of the prevalence of a duodecimal modulus in many other popular measures.

The subsequent addition of the five complementary days is attributed to an Egyptian god or hero called by the Greeks HERMES, with the distinguishing appellation of TRISMEGISTOS, *thrice-greatest.*

75. This interval of 365 days was as near an approximation to the period of the seasons as could be made in round numbers. Nevertheless its continuance would, after the lapse of a certain time, have been the cause of inextricable confusion. Let us see whether we cannot make this apparent.

The true period marked by the return of the seasons is now known to differ from 365¼ days by a little more than eleven minutes. This difference, minute as it is, has been the cause of great difficulties in history and chronology. Let us, however, for the present put it out of view, and take the year as being 365¼ days exactly.

After the lapse of one year of 365 days the seasons would, therefore, return a quarter of a day later than in the preceding year. After another year of 365, they would return half a day later; after another, three-quarters of a day later; and after four years they would be an entire day later. Thus if spring began in the first year on the 21st March, it would begin in the fourth year on the 22nd March. In like manner it would begin in the eighth year on the 23rd, in the twelfth, on the 24th, and so on; being one day later every fourth year. In 30 times four years it would be a month later; and in 182½ times four years—that is in 730 years—it would be just six months later, so that Spring would commence on the 21st September, and Autumn on the 21st March. The first day of Summer would be 21st December, and the first day of Winter would be 21st June.

Such would be the ultimate effects ensuing from the adoption of a year of 365 days.

The confusion, historical and chronological, which would ensue from such a method of recording time must be obvious. If we found any event recorded in remote times which might have been affected by the season of the year at which it occurred, its date would supply no immediate indication of that. For anything indicated by the month in which it took place, it might have been in any season whatever, Spring, Summer, Autumn, or Winter. It is true, however, that the season might be discovered from the date, by calculating backwards, and allowing a day for every four years.

It is clear that after a period of four times 365 years—that is 1460 years—the seasons would return to the same days, having in the interval commenced upon every day of the year from the first to the last.

76. This discordance between the year of 365 days and the period of the seasons caused the former to be called the *Vague year;* the period of 1460 years, after which the seasons would return to the same days, was called the SOTHIC PERIOD, from some supposed relation to the *dog-star*, called SOTHIS.

77. However obvious were the objections attendant on the adoption of the year of 365 days it was not without defenders and partisans. The advantage claimed for it will, in our times, appear curious. It was said that such a year would cause all the festivals to fall successively upon every day in it, and would thus sanctify the entire year; just as if a Christian would at present advocate it on the ground that Christmas would in the course of fourteen or fifteen centuries fall upon every day in each season, of spring, summer, autumn and winter!

78. The Greeks, as we have seen, first measured time by months consisting alternately of 29 and 30 days, giving an average of 29½ days, a very close approximation to the true mean length of a lunation, and their year consisted of twelve such months. Such a year, however, consisting of only 354 days, deviated from the

periodic return of the seasons by more than eleven days, and after the lapse of no more than three years the seasons were put back more than a month; and after a period of eighteen years they were actually reversed, midsummer taking the place of mid-winter, and *vice versâ*. The return of the seasons constituted so obvious and so natural a measure of the year, and was so intimately connected with the prosecution of human affairs, and especially with agriculture, that no measure of the year which varied so much from it could be long maintained; and, as we have already stated, attempts were soon made in all the provinces of Greece to bring the series of twelve months into accordance with the period of the seasons, by adjusting their several lengths so as to make a total of 365 days: an interval so near the true succession of the seasons that an age must elapse before any important discordance would have been rendered manifest.

Religious questions, however, intervened and raised serious difficulties among the Athenians. The festivals and ceremonies connected with the worship of the gods all originated at an early epoch when the lunar phenomena alone formed the basis of their chronology. Certain observances were required to be made in certain phases of the moon, and when those phases, by the changes in the lengths of the months, no longer recurred upon the same days of the year, but assumed a character similar to that of the moveable feasts of the Christian church, it became necessary in order to fix beforehand the times of their celebration, to calculate the days of the lunar phases, and, in a word, to create a calendar.

The difficulties which thus arose in the imperfect state of astronomical science at that epoch were seriously aggravated by a command proceeding from an oracle, to the effect that certain festivals appointed to be celebrated under particular lunar phases should be also held at certain seasons of the year. This at once rendered necessary the solution of the problem to bring into numerical accordance the series of lunations and the succession of the seasons, a problem which was at the time as far removed beyond the skill of the astronomers as that of the priests.

79. At length, about 432 B.C., Meton, an ancient astronomer, succeeded in obtaining a solution of it which, if not absolutely complete, was regarded as so satisfactory as to excite an outburst of popular enthusiasm. He stated that 235 lunations were exactly or so nearly equal to nineteen years that at the end of that period the full moons would again fall upon the same days of the year, and that, consequently, if the series of full moons were recorded for any single period of nineteen years, indicating the days upon which they severally took place in each year, they must recur upon the same days in every succeeding period of nineteen years,

and must have in like manner occurred upon the same days in every past period of nineteen years. Thus all calculation of the recurrence of the lunar phases was rendered unnecessary. The lunar calendar of any interval of nineteen years was merely a reproduction of the lunar calendar of the preceding interval.

This period of nineteen years was, and is still, called the METONIC CYCLE.

80. This discovery which was made public by Meton on the occasion of the celebration of the Olympic games in 432 B.C., excited such unbounded enthusiasm and admiration, and the benefits it conferred upon chronology were so highly appreciated, that the numbers expressing the dates of the full moons in a cycle were ordered to be inscribed in letters of gold upon the public monuments, and upon tablets in the temples of the gods. It is to this circumstance that is ascribed the fact that these numbers were afterwards usually written in the almanacks in gilt characters, and later when printing had been invented, they were distinguished by being printed in red ink, and they thus acquired the name of golden numbers, by which they are distinguished in the calendars of the present day.

81. Neither the brilliancy of this discovery, nor the glory of the Olympic crown, nor the great popularity with which he was surrounded, protected Meton from the shafts of his illustrious contemporary Aristophanes, who attempted to turn him into ridicule and bring him into discredit by introducing him among a group of charlatans in the well-known comedy entitled "The Birds" (Ορνιθες).

82. It is a curious fact that the accordance of the succession of the lunar phases with the Metonic cycle has become more and more precise, as the motions of the sun and moon in the heavens have been more exactly ascertained. The mean length of a lunation, which was already known in Meton's time with great precision, is 29·530589 days, and consequently 235 lunations consist of

$$29{\cdot}530589 \times 235^{d} = 6939^{d}\ 16^{h}\ 31^{m}\ 19^{s}.$$

The mean length of the year, which was not so well ascertained in Meton's time, is now known to be 365·24224 days, or

$$365^{d}\ 5^{h}\ 48^{m}\ 49{\cdot}5^{s},$$

and consequently nineteen such years consist of

$$(365^{d}\ 5^{h}\ 48^{m}\ 49{\cdot}5^{s}) \times 19 = 6939^{d}\ 14^{h}\ 27^{m}\ 41^{s},$$

from which it appears that 235 lunations exceed nineteen years by $2^{h}\ 3^{m}\ 38^{s}$.

After each interval of 19 solar years, therefore, the successive lunations would commence $2^{h}\ 3^{m}\ 38^{s}$ later.

83. It has been already stated that the Roman year consisting

first of 304 days, was immediately increased to 355 days; and that ultimately, by the complementary month called Mercedonius, 45 days were added to every fourth year. Thus each series of four years consisted of

	DAYS.
I.	355
II.	355
III.	355
IV.	400
	1465

So that the four years consisted of 1465 days.

The true length of four solar years being, however, only 1461 days, four Roman years as thus established would be four days too long; so that every four years the seasons would fall four days earlier in the year, and in the short period of thirty years, they would be severally moved back a month.

84. This consequence being soon rendered apparent, a remedy for it became necessary, and that which was first adopted was one of the worst expedients that could have been imagined. A discretionary power was given to the pontiffs to intercalate as many days as they might consider necessary to bring the year into accordance with the succession of seasons.

As might have been foreseen, this measure speedily gave rise to the most gross system of abuses. Accounts being made up, payments made, and interest computed for all affairs private and public to the first days of the months, the pontiffs prostituted the powers conferred upon them to the most corrupt purposes. The temporary magistracy of those whom they favoured was prolonged, and that of those whom they opposed was abridged; payments to be made by their friends were postponed, those due by their opponents accelerated; the profits of the farmers of the revenue were augmented or diminished at their good will and pleasure, by the adroit management of the arbitrary intercalary days by which they were enabled to prolong or to abridge any months of the years. The disorders thus produced attained at length to such a pitch, that the festivals of autumn were celebrated in spring and *vice versâ*.

VII.—THE JULIAN REFORM.

85. It was reserved for Julius Cæsar not only to put an end to this confusion and the abuses in which it originated, but to establish a system of recording time, which has come down to our own epoch, and is denominated from its founder the JULIAN CALENDAR. He was aided in this great reformation by Sosigenes, an eminent

Egyptian astronomer of that day. He was, according to the laws, authorised to accomplish this, being himself chief pontiff.

Astronomical science had so far advanced, that the length of the period determined by the succession of the seasons was known to be about 365¼ days. But the adoption of a civil year conforming to this would have involved consequences of a highly impracticable kind. Thus, if we suppose such a year to commence at midnight, between the 31st December and 1st January, the succeeding year would commence at six A.M. on the next 1st January; the next at noon, on the following 1st January; the next at six P.M., on the 1st January of the third year; and, in fine, the next at the midnight between the 1st and 2nd January on the fourth year. Thus, in a series of four years, the first day of January would be transferred piecemeal, quarter by quarter, backwards to the preceding year.

This was evidently an impracticable measure. Julius Cæsar, who in the eminently practical character of his genius closely resembled Napoleon, resolved upon surmounting the difficulty by an expedient as simple in its execution as it was happy in its conception.

86. It was decided to adhere to years consisting of a whole number of days, and to allow the fractions to accumulate from year to year, until they should make up an entire day, and then to add that as a supplemental day to the year in which the accumulation should arrive at its limit. Since therefore the fraction over the round number of 365 days was assumed to be a quarter of a day, it would at every fourth year amount to a day. It was, therefore, decided to accomplish the object by giving one additional day to such fourth year. These four successive years were to be thus composed:—

	D.
I.	365
II.	365
III.	365
IV.	366
	1461
Mean length	365¼

The object was, therefore, attained without annexing fractional parts of a day to the year.

The additional day given to the fourth year was introduced into the month of February, making that month 30 instead of 29 days.

COMMON THINGS.

TIME.

CHAPTER IV.

87. Year of confusion.—88. New arrangement of the months.—89. Mistake of the Pontiffs.—90. Leap-years.—91. Historical dates.—92. Day of the equinox.—93. What is the equinox?—94. The two equinoctial points.—95. Sidereal year.—96. Precession of the equinoxes.—97. Equinoctial year.—98. Civil year.—99. Difference between it and the Julian year.—100. Effect of this difference.—101. Cause of the reformation of the Calendar.—102. Discordance between the real and ecclesiastical equinox.—103. Gregorian reform.—104. Gregorian Calendar.—105. Its compensating effect.—106. Resistance to its adoption.—107. Dates of its adoption in different countries.—108. In England.—109. Its reception there.—110. Occasional agreement of the new and old styles.—111. Anecdotes relating to the change.—112. Russia adheres to the old style.—113. Commencement of the year.—114. Various in different countries.—115. In England.—116. Old and new style in England.—117. Temporary inconvenience attending it.

It will be remembered that the Romans counted the days of the month backwards, and that those of the latter part were reckoned from the calends or first day of the next month. Now it happened that the sixth day of February, counting backwards from 1st March, called the sexto-calendas was consecrated to a festival celebrating the expulsion of the Tarquins. It was resolved to place the supplementary day of the fourth year immediately before this sexto-calendas, and to avoid changing the denomination of the other days it was decided to call it a second sexto-calendas. It was therefore denominated BISSEXTO-CALENDAS, and the year in which this additional day was intercalated was and still is called A BISSEXTILE YEAR.

The commencement of the year was ordered to take place on the day of the new moon, which occurred next after the winter solstice of the preceding year. This day was accordingly called the 1st January, 709, from the foundation of Rome, and as the commencement of our era was the year 754 from the foundation of Rome, it follows that the date of the Julian reform was 45 B.C. and consequently the year preceding the murder of Cæsar.

87. This admirable arrangement provided for the future, but it did not repair the consequence of the past abuse and disorder. The complementary month called Mercedonius had been the subject of constant maltreatment by the pontiffs, having been abridged and extended in the most capricious and arbitrary manner, so as completely to derange the position of the seasons, relatively to the commencement and the close of the year. To rectify this some bold and exceptional temporary measures were indispensable. Cæsar being chief pontiff exercised the power which his predecessors in that office had so grossly abused to rectify these disorders, and restored by a violent and exceptional measure the day of the spring equinox to the 25th March, the date which it held in the time of Numa. To accomplish this, he decreed that the year 708 from the founding of Rome should consist exceptionally of 445 days. These 445 days were composed in the following manner:—

		Days.
The common year		355
Month Mercedonius		23
Two extraordinary months between November and December:	First	33
	Second	34
		445

The year in which these changes were introduced came to be called the "YEAR OF CONFUSION." This year was 46 B.C.

88. Besides thus re-adjusting the place of the equinoxes, the

distribution of the 365 days among the twelve months was rearranged. It was ordered that the odd months, counting from the beginning of the year should contain 31 days each, and that the others should contain 30, except February, which in common years was to contain 29, and in bissextile years 30 days.

This natural and easily remembered distribution was disarranged soon after to gratify the frivolous vanity of Augustus. It has been already stated that the month Sextilis had its name changed to Augustus in compliment to that emperor. Not satisfied with thus having his name perpetuated, he insisted that the number of days in his month should not be less than in Cæsar's. The day added to August was therefore taken from February, which was thus reduced to 28 days for common, and 29 for bissextile years. The months definitively stood as follows :—

	Days.		Days.
January . . .	31	July	31
February . . .	28 or 29	August	31
March . . .	31	September . . .	30
April . . .	30	October	31
May . . .	31	November . . .	30
June . . .	30	December	31

The alternation of 30 and 31 days proposed by Cæsar is therefore preserved with the exception of July and August, two months of 31 days in immediate succession.

It was attempted at later periods of the empire to prostitute the calendar by changing the names of the latter months of the year into those of Tiberius, Claudius, Nero, and Domitian; but the good sense of the Roman public resisted such an ignominy.

89. The death of Cæsar in the year after this reform had been decreed, threw the task of its realisation into the hands of the pontiffs, whose very first act betrayed a total misapprehension of the meaning of the most important of the conditions of the new system. The terms of the Julian edict, by which the recurrence of the bissextile year was defined, have not come down to our times; but it is certain that the pontiffs interpreted the periodic addition of the intercalary day as designed for every third year, and not every fourth year. That they were not set right by any contemporary authority like Sosigenes, who, knowing the object to be accomplished by the expedient, might have demonstrated the sense of the edict, if the words in which it was expressed were equivocal, only shows in a striking point of view how rare this sort of knowledge must have been in that age. However, it is certain that for the first 36 years after the reformation, every third, instead of every fourth year, was taken as a bissextile year, and consequently that these 36 years, including 12 instead of 9

intercalary days, had a total length greater by 3 days than was due to them by the Julian system rightly understood. When this error was at length perceived, the consequence of it was rectified by order of Augustus, who decreed that for three successive periods of four years, the intercalary day due to every fourth year should be omitted, so that the excess given to the preceding 36 years was compensated by an equal deficiency in the 12 following years, after which the regular recurrence of bissextile years was observed.

The mistake is known to have arisen thus—In Roman counting, every *fourth* is our *third*,

			1	2	3	4			1	2	
A	B	C	D	E	F	G	H	I	J	K	&c.
1	2	3	4			1	2	3	4		

Livy describes the cycle of 19 years as *one which* begins every *twentieth* year.

90. The common name given to bissextile years in our language is LEAP YEARS, which the dictionaries explain by stating that "every fourth year leaps over a day more than a common year." It is, however, objected by some that the term LEAP year is inappropriate, inasmuch as leaping over a day would imply its omission, instead of which in such years an extra day is thrust in.

The term is also explained by stating, that it implies that a day is leaped over in the calendar without giving it a distinct name.

It is worthy of remark that in the ecclesiastical calendar of foreign countries, the day called "intercalary" in bissextile or leap years, is not the 29th but the 24th of February.

91. It will be perceived from what has been stated, that some confusion prevailed for nearly forty years from the date of the Julian reform, that is until very near the commencement of the Christian era; nor is there any historical certainty as to the regular observance of the new method until the commencement of our era. It is certain, however, that the Roman years 761, 765, 769, &c., which were the years A.D. 8, 12, 16, &c., were counted as leap years, and about all succeeding dates there is no doubt.

From these dates, historians and chronologists have reckoned not only forwards but backwards, so as to reduce all historical events to the position in respect to the order of time which they would have held, if the Julian system had always existed. When we read of historical events, occurring in distant ages before these reforms in the methods of recording time, we are to understand that the dates assigned to them are by no means those which they bore at the time, and in the nation of their occurrence; but that by the labours of chronologists, the local dates given to them by the contemporary annalists, dates varying not only in different countries according to their different usages, but even in the same country in different ages, have been changed into those dates which they would have had if the Julian chronology had prevailed then.

It is evident that without this simplification and assimilation, historical dates would present a mass of confusion, which would be inextricable to all ordinary readers.

92. It has been already stated that the interval of 365¼ days, assumed in the Julian reformation as the length of a year, is not its true length, but differs from it by a very small fraction of a day. As we have now to explain the part which this very minute fraction has played in chronology, it will be necessary to convey to the reader a more clear and distinct notion of the meaning of the word *year*, than that which is included in the general statement that a year is the period after which the seasons are reproduced; for it may fairly be asked what determines the limits of the seasons? how are the exact moments of time at which they severally begin or end defined? For it must be observed that our enquiries now involving not whole numbers of days, but small fractions of a day, it is not enough to know that this or that season begins or ends on this or that day; we must know the hour, minute, second,—nay even the fraction of a second, which marks the epoch we desire to determine.

It is customary then to define the course of the seasons by the moment at which spring begins. It has been agreed to take for this the moment at which the centre of the sun's disc has such a position in the heavens, that if it were stationary there, day and night would be exactly equal, that the sun would be in short exactly twelve hours visible, and twelve hours invisible; twelve hours above, and twelve hours below the horizon.

It may be said that this definition is needlessly verbose and complex, inasmuch as it would be more simple and intelligible to say at once that spring begins *on the day of the equinox*.

Undoubtedly such a summary statement would be much shorter and more simple, and provided that it be clearly understood, and that it be sufficiently definite, it can be subject to no objection. But what is meant by the "day of the equinox?" We shall, of course, be answered that it is that day on which the sun is twelve hours above, and twelve hours below the horizon.

Very well! let us go to the almanac, and search for such a day. We take the almanac of 1854, and find that on 19th March the sun was twelve hours and one minute above, and eleven hours and fifty-nine minutes below the horizon. On the 20th it was twelve hours and six minutes above, and eleven hours and fifty-four minutes below the horizon, while on the 18th it was eleven hours and three minutes above, and twelve hours and fifty-seven minutes below the horizon. On no day of the month was it exactly twelve hours above, and twelve hours below the horizon; and the same result would be found by examining in the same manner the almanacs for other years.

It appears then that rigorously equal day and night is a phenomenon that never exists. It is no answer to this to say that the day and night in the instance produced and others differ only by a minute or two, because the question here involves only the consideration of those very minute intervals.

Since then the "day of the equinox" cannot mean a day on which day and night are equal, what is its exact meaning? We reply that it means very obviously the *day on which the equinox takes place.* But then what is in that case meant by the word equinox? We reply by turning back upon the explanation already given, that the equinox is that precise moment when the centre of the sun's disc has such a position that, supposing it to retain that position unchanged, it would be twelve hours above, and twelve hours below the horizon, during a revolution of the heavens.

93. But since the sun's disc has a continual easterly motion upon the heavens, moving at the rate of nearly 1° per day, or $2\frac{1}{2}'$ per hour, it does not retain the position in question more than an instant. It moves round the heavens as the hand of a clock moves round its dial, passing incessantly from point to point. The exact point at which the centre of the sun is at the moment above described, is therefore called the equinoctial point, as the moment of time at which it passes through that point is called the equinox.

94. There are two equinoxes and two equinoctial points. The first takes place about the 21st March, and the other about the 23rd September.*

The former is called the vernal equinox, and the latter the autumnal equinox, because it has been agreed to fix the beginning of spring at the one epoch, and the beginning of autumn at the other.

The two equinoctial points are situate at opposite sides of the heavens, separated one from the other by an entire hemisphere, as must be evident when it is considered that the sun takes six months to move from the one point to the other.

95. Having thus conveyed a distinct notion of the meaning of the equinoxes, and of the equinoctial points, we shall find less

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* In the tables of sunrise and sunset given in the almanac, the effects of refraction are taken into account. These are omitted, however, in fixing the position of the equinoxes.

difficulty in explaining the different senses in which the word YEAR is used.

If the equinoctial points maintained a fixed position on the heavens, the interval between the moments at which the centre of the sun's disc would pass twice successively through either of them, would be in fact the interval during which the sun makes or appears to make a complete revolution of the heavens.

This interval is called the SIDEREAL YEAR.

Astronomers have ascertained the exact length of this year to be $365^d\ 6^h\ 9^m\ 10{\cdot}38^s$.

It appears, therefore, that this long interval has been ascertained to within the hundredth part of a second of its true value.

96. But the equinoctial points have not a fixed position on the heavens. They are on the contrary, subject to a slow displacement from year to year in a direction contrary to the motion of the sun. The amount of this annual displacement is small, being a little less than one minute of a degree,—that is, about the thirtieth part of the breadth of the sun's disc.

Small as this displacement is, it has been very precisely measured; and its effects, which are of the highest importance, as well in chronology as in astronomy, have been exactly appreciated.

On account of this removal of the equinoctial point backward, the sun arrives at it after making a revolution of the heavens, sooner than it would have done if it had not been displaced. This must be evident when it is considered that the equinoctial point, displaced in a direction contrary to that of the sun's motion, advances to meet the sun on its return. The sun therefore arrives at it before it makes a complete revolution of the heavens, and the time of each successive equinox *precedes* the time at which it would have taken place if the equinoctial point had been stationary.

This phenomenon has for that reason been called the PRECESSION OF THE EQUINOXES.

97. The effect therefore obviously is, that the interval between two successive equinoxes is less than the sidereal year.

This interval between two successive equinoxes is called the EQUINOCTIAL or TROPICAL YEAR.

The sidereal year is of invariable length, and would on that account be well suited to be a standard measure of time. But it has one capital defect, which renders it totally unfit for civil purposes. It is not in accordance with the periodic returns of the seasons by which all mankind measure the year.

If the equinoctial points were stationary, the sidereal year would also be the equinoctial year, and in that case it would be coincident with the return of the seasons. But in consequence of the displacement of the equinoctial points, the commencement of the equinoctial anticipates that of the sidereal year; the extent of this anticipation, though very small at first, accumulating for long series of years, causes the seasons to take place successively at all imaginable parts of the sidereal year.

For these reasons the sidereal year has never been adopted as the civil year.

If the annual displacement of the equinoctial point were regular and constant, the precession of the equinoxes would be also constant; and the equinoctial year, differing from the sidereal year by an invariable quantity, would itself be invariable, and as it is in accordance with the succession of the seasons, it would be in all respects eligible as a standard measure of civil time.

But it so happens that this displacement is rendered variable by the operation of several causes. Its variations, however, are circumscribed within narrow limits. It alternately increases and decreases, and has a certain ascertainable average amount. On account of this variation, the equinoctial year is of slightly variable length, and is therefore not fit for a standard measure of time.

98. This being the case, and the mean annual displacement of the equinoctial point being accurately ascertained, a fictitious equinoctial point is supposed to exist, which has this mean annual displacement, and the interval between two successive returns of the sun to this fictitious equinoctial point being invariable, is adopted as the standard, and is called the MEAN SOLAR OR CIVIL YEAR.

Although rigorously this year does not therefore correspond with the returns of the seasons, it never varies from them by any interval great enough to be perceived or appreciated by any but astronomers.

The exact length of the mean solar or civil year is

$$365^{d}\ 5^{h}\ 48^{m}\ 49^{s}{\cdot}54,$$

being less than the sidereal year by $20^{m}\ 20^{s}{\cdot}8$.

99. Such being then the actual length of such a year as would always remain in accordance with the successive returns of the seasons, let us see to what extent the year of the Julian calendar differs from it, and how such difference would affect chronology.

The Julian year being 365¼ days, the difference between it and the mean solar year is easily found.

	D.	H.	M.	S.
Julian year	365	6	0	0·00
Mean solar year . . .	365	5	48	49·54
Difference			11	10·46

100. It appears, therefore, that the Julian years would depart from the course of the seasons at the rate of $11^{m}\ 10^{s}{\cdot}46$, or about

the 129th part of a day per annum. The departure accumulating from year to year would amount to a whole day in 129 years, to two whole days in 258 years, to three in 387 years, and so on.

Now, although such a departure would not be perceptible during the lives of a single generation, it must evidently become so after some centuries. The equinox falling back towards the beginning of the year at the rate of one day in 129 years, was in the fifteenth century thus thrown back as much as eleven days.

It is evident that the continuance of this from century to century would have thrown the equinox back from day to day until it, and consequently the seasons, would have successively assumed every possible position in the year.

VIII.—THE GREGORIAN REFORM.

101. Although in a more civilised and enlightened age this would have been a reason sufficiently urgent to undertake a revision and correction of the calendar, we are indebted for the reform which took place to other and different causes.

102. It was the rule of the Church to celebrate the festival of the Resurrection at a time not far removed from the 21st March, which was taken to be the day of the equinox, depending however also upon conditions connected with the lunar phenomena with which we are not at present concerned, but which we shall explain fully on another occasion. If therefore the real equinox were subject, as we have stated, to a gradual change, which would throw it back from year to year, so that it would fall each successive year earlier and earlier, while the festival of Easter, still related to the 21st March, would necessarily be farther and farther removed from the equinox, it must obviously happen in the course of time that the festival would fall successively in every season of the year, and indeed on every day of the year.

The Roman ecclesiastical authorities of the day becoming painfully aware of this, and sensible that no decree of pope or council could accelerate the motion of the equinox for the future, or carry it forward from the 11th to the 21st March; to repair the error of the past, resolved that since they could not bring the equinox to the 21st March, they would bring the 21st March to the equinox.

103. This change, with the others necessary to prevent the recurrence of a like discordance between the ecclesiastical year and the seasons, took place in the latter part of the sixteenth century, in the pontificate of Gregory XIII., from whom the reformed calendar came to be called the Gregorian calendar.

As at the epoch of the Julian reform, two errors were to be corrected, those of the past and those of the future. The accumulated effect of the past errors was that the real epoch of the spring equinox had fallen ten days behind the nominal day of its occurrence, which was the 21st March. The future cause of error was that an additional day every fourth year was too much, but that 129 years must elapse before the redundancy would cause the equinox to be one day behind its time.

104. To remedy the consequence of past errors, it was decreed that the days of the months should be all expressed by numbers, greater by 10 than those by which, according to the succession of time, they were expressed. Thus the 11th March, 1582 (the year in which the reform took place) was decreed to be the 21st March, and in like manner all the other days of the year were augmented by 10. By this expedient the last ten days of 1582 were thrown over into 1583, inasmuch as the 21st December, 1582, became 31st December, 1582, and consequently 22nd December, 1582, became 1st January, 1583.

The day of the vernal equinox thus recovered the date of 21st March. How it was secured in the undisturbed possession of that date, we shall now see.

By following the established rules of the Julian calendar, it would have been one day behind its date in 129 years from 1582, that is in 1711. To prevent this, it was decreed that the year 1700, which would by the Julian calendar be a leap year, should be a common year. One day being thus omitted, the equinox of 1711 would be restored to its date of 21st March. In like manner it would be again a day behind in 1840. This was in like manner to be prevented by making 1800 a common year, which ought to be a leap year. Again it would be a day behind its time in 1969, which would be set right as before by making 1900 a common instead of a leap year. Another period of 129 would go to 2098, which was remedied by making 2100 a common instead of a leap year.

Thus the equinox would be kept right by making three successive secular years 1700, 1800, and 1900 common years instead of leap years, leaving 2000 a leap year, but making 2100 a common year instead of a leap year, and going on from century to century in the same manner, leaving every fourth secular year a leap year, but making all the others common years. The series of secular years would therefore be as follows:—

1700 Common
1800 ,,
1900 ,,
2000 Leap
2100 Common
2200 ,,

2300 Common
2400 Leap
2500 Common
2600 ,,
2700 ,,
2800 Leap,

and so on. The secular leap years will always be those of which the first two figures are exactly divisible by 4 without a remainder, as 2000, 2400, 2800, 3200, 3600, &c., all the other secular years being common years.

105. Let us see whether the compensation thus produced for the errors of the Gregorian calendar is practically sufficient, for perfect it is not, nor is it possible for any such compensation to be so. It has been shown, that the Julian year was too long by the 129th part of a day very nearly. To compensate for this Pope Gregory XIII. does what? He takes away three days from 400 years, which is equivalent to taking $\frac{3}{400}$th part of a day from one year, whereas the quantity required to be deducted is the 129th part of a day, which is greater than the $\frac{3}{400}$th part. The compensation of Pope Gregory is therefore short of the requisite quantity by the difference between the 129th and the $\frac{3}{400}$th part of a day, that is by the 3969th part of a day.

Thus it appears that by following the Gregorian calendar the equinox will not be so much as one day behind its time until an interval of 3969 years elapses, counting from the year 1582, that is until the year of our Lord 5551. When that time arrives the evil may be staved off for another period of 3969 years, by declaring the year 5600 a common, instead of a leap year. We may, however, safely leave to the inhabitants of the earth at that epoch the management of the affair. Sufficient for the day is the evil thereof.

106. Notwithstanding the undeniable reasonableness of this reform of the calendar, and the manifest absurdity of persevering in calling the 21st March the vernal equinox, when all the world had the evidence of their senses to prove to them that the equinox had really taken place ten days earlier, the change proposed was not generally adopted. Protestant States were opposed to it because it emanated from Catholic ecclesiastical authorities, and as was wittily observed, they preferred rather to be in opposition to the sun than in accordance with the Pope. The nations professing Greek Catholicism were opposed to it because it emanated from the head of the branch of their Church which they denied to be orthodox.

The papal decree fixed the exact date of the commencement of the reform at the 5th October, 1582, according to the former style, which day was decreed to be called the 15th October.

107. In France the change was adopted on the 10th December, next following, which was called 20th December.

In the Catholic States of Germany it was adopted in 1584.

The Protestant German States, having resisted the reform for nearly twenty years, at length yielded, and accepted it in 1600, in which year the 19th February was declared to be 1st March.

Denmark, Sweden, and Switzerland, were later in the adoption of the change, but soon followed the example of Germany. Some Swiss towns nevertheless offered such vigorous opposition to the measure, that the intervention of the military was necessary to enforce it when adopted by the authorities.

In Poland, where it was adopted by the government as early as 1586, it encountered considerable opposition in certain towns, and even excited a serious insurrection at Riga.

108. The anti-papal spirit being much more dominant in England than common sense or scientific authority, the reform was resisted for nearly two centuries, so that the real had fallen above eleven days behind the legal date of the equinox. In 1752, however, the force of things at length prevailed over this discreditable bigotry, and the reform was introduced into the calendar, by declaring the 3rd to be the 14th September.

109. A measure of which the effect was to overturn the long established landmarks of time, and to substitute for them others, new and altogether strange to tradition and usage, could not be supposed to pass without exciting many reclamations among persons of all classes from the peer to the peasant. Personal feelings were excited at the unceremonious perturbation of birthdays and of marriage anniversaries. Religious exasperation was produced by the arbitrary transposition of the most solemn festivals. Even the moveable feasts already surrounded with some confusion, became for the moment confusion worse confounded. Political celebrations and the dates of historical events shared in the general disturbance.

In an essay on the ecclesiastical calendar, by Professor De Morgan, which was published in the Companion to the British Almanac, for 1845, some amusing examples of this are collected. A friend of the author, an eminent scientific man, not long since deceased, related of his own knowledge, when a boy, that a worthy couple in a country town, scandalised at the change of style in 1752, continued to attempt the observance of Good Friday on the old day. To this end they used to walk seriously, and in holiday costume, to the church door, at which the gentleman used to knock for a certain time with his cane, demanding admittance. On finding no admission, they walked as solemnly home again, and read the Church service appointed for the day. On the new and, as they regarded it, spurious Good Friday, they ostentatiously acted as if it either preceded or followed the genuine day, as the case might be, so as to render it manifest to their neighbours and friends, that they at least totally rejected the new style.

110. In the 48 years, between 1752, the date of the change of

style, and the end of the century, there were, however, 18 years in which harmony must have been re-established between the partisans of the new style and those who reverenced tradition, for in these years it chanced that the moveable feasts, according to both styles, fell upon the same days. "This," observes Professor De Morgan, "happens still occasionally, and will do so, though less and less frequently, until 2698 A.D., when it will happen for the last time."

Even still, after the lapse of more than a century, the Christmas Day of the old style is celebrated under the name of Twelfth Day, and the name of "Old Christmas Day" is still given to it in the calendar. It falls on the Feast of Epiphany.

111. Before the change of style, a popular belief prevailed in England, that at the moment of the midnight with which Christmas Day began, the cattle always fell on their knees in their stalls. Now when the change of style took place, it could scarcely have been expected that the arbitrary will of the legislature would be respected by these dumb animals, and it was accordingly found that they continued to perform the act of reverence, not on the Christmas Day of the law, but on that of the old style! The best of this joke was, however, that the Christmas Day of the law was a Popish institution, forced upon England by circumstances, and it was maintained that these Protestant cattle were all the more obstinate in their dumb protestation against the Romish innovation.

It appears, nevertheless, that in Catholic countries which acknowledged the authority of the See of Rome, in changing the style in 1582, inanimate things, not to say cattle, acknowledged the validity of the decree; for we have the high authority of the truly learned Riccioli, to whose astronomical works the scientific world is so largely indebted, to assure us that the blood of St. Januarius, which previously used to liquefy punctually on the 19th September, immediately changed the day of its miraculous liquefaction to the 19th September of the new style, which was the 9th September of the old style. Like the day of the nominal equinox, that of the miracle was accordingly put back ten days, in obedience to the papal bull.

Riccioli also mentions the case of a certain supernatural twig, which had been accustomed to put forth miraculous buds on Christmas Day. This Romish twig, unlike the Protestant cattle, as the astronomer assures us, was found to bud on the new Christmas Days which followed the publication of the Papal bull.

112. Of all Christian States, Russia alone still insists on adhering to the Julian calendar, and accordingly, by the further

accumulation of the effects of the erroneous length assigned to the year, the Russian legal equinoxes are now *twelve* days in advance of the real equinoxes.

113. The influence which long continued usage exercises upon the mind is such that we are always disposed to think, that what has been long established has been so by the nature of things, and therefore of necessity, and not at all by the arbitrary appointment of local and temporary authorities, or by the voluntary choice of the people. Thus, who does not imagine that it is for some natural and necessary reason that the year begins on the 1st of January? January is the first of the series of twelve months, and what can be more natural than to take its first day as the commencement of the year? But why is January the first month? It is marked by no peculiar or universally observable phenomenon. If the sun, on its first day, were seen to occupy any remarkable position, as, for example, that which it has at the equinox, or if the sun and moon were always found together on that day, or if a conspicuous eclipse, or any other striking phenomenon periodically presented itself on that day, a reason would be found why January is the first month, and why its first day is the first day of the year. But neither the month nor the day is signalised by such phenomena, nor by any which can be supposed to mark it by nature as the commencement of a chronometric period.

It might be imagined that at all events the first day of *some* month would be selected as the commencement of the year. No reason, as it would appear, could induce people to begin the year in the middle of a month, so that one part of that month should be in one year and the remainder in the other. Nevertheless, obvious as these considerations now appear, it is certain that they have had no weight with mankind. Other considerations of another order, exercising over the mind much more potent influences, have predominated, and years, accordingly, with different nations and in different ages, have had their commencement fixed upon days which have no reference either to astronomical phenomena, or the order or limits of the months.

114. Religious anniversaries, as might naturally have been expected, have played a prominent part in this chronological element. Christmas Day, Easter Day, and the Festival of the Annunciation, commonly called Lady Day, have been, in different countries and at different ages, selected as the first day of the year. Among the French, at the time of Charlemagne, the year commenced on Christmas Day. It commenced on Easter Day among the same people under the Capet monarchs, and this practice was very general in the twelfth and thirteenth centuries. In

England the year commenced on Lady Day (25th March) until 1752.

It must not be understood that this commencement of the year involved any change either in the months or in the order of their days. Thus when the year commenced on Christmas Day, that day was still called the 25th December, and was preceded by the 24th and followed by the 26th December; but the 24th December belonged to one year and the 25th to the next. In like manner, the two days which we now refer back to as the 24th and 25th March, 1751, were, at the time they actually occurred, called the 24th March, 1750, and 25th March, 1751. Thus 24 days of March belonged to 1750, and the remaining 6 days to 1751.

115. To us at present, with the habits of counting the years, months, and days to which we have been accustomed, such a method of commencing the years appears so absurd and attended with such strange confusion and disorder that we find it difficult to imagine how a people could ever continue the practice of it. Nevertheless it is certain, so far from any such impression existing at the time this usage prevailed, the announcement of the change of style, as it was called, which was decided upon by the legislature in 1751-2, encountered the most serious resistance, and excited popular disturbances of grave importance. The transfer of the beginning of 1752 from the 25th of March to the 1st of January, immediately preceding it, deprived the year 1751 of the months of January, February, and twenty-four days of March, nearly the whole of its three last months.

This change and the apparent sponging out from the course of time of eleven days exasperated the populace, who, assembled in the streets of London, and pursued the members of the government (among whom was the celebrated Lord Chesterfield) when they appeared, with cries and imprecations, demanding that their eleven days should be given back to them.

The traces of this custom in our country are still apparent in various practices. Leases are commenced and determined by Lady Day. The quarter days on which rents become due are regulated in the same manner. All rents are payable on Lady Day and Michaelmas Day, and not, as might naturally be expected, on the last days of June and December.

116. Until the adoption of the Gregorian calendar in England in 1752, the years, as has been already stated, commenced upon the 25th March, so that the year 1751 began on the 25th March, 1751, and ended upon the day now called the 24th March, 1752, while the year 1752 ended on the day now called the 24th March, 1753. Independently of the other obvious objections to such a system, it was out of all accordance with the mode of reckoning time prac-

tised by other nations of Europe, and great inconvenience and some confusion prevailed in the adjustment of dates in all international transactions. It was therefore resolved to include in the reformation of the calendar the change of the commencement of the year, from the 25th March to the 1st January, which was accomplished by declaring that the days, from the 1st January, 1751 (as formerly counted) should be taken as belonging to 1752, and that 1752 should end on the 31st December, and 1753 begin on the day formerly called the 1st January, 1752. Thus, in fact, the months of January, February, and twenty-four days of March, were transferred from each year to that which succeeded it.

This will explain the peculiar way of expressing dates which is found in all documents and printed works which appeared at, and for some time after the reform was adopted. Both dates, the new and the old, according to the reformed and unreformed style, were usually expressed, the old above and the new below a line, like the numerator and denominator of a fraction. Thus, for example, the day which was the 19th June, 1753, in the old style, being the 30th June, 1753, in the new style, the date was written thus, $\frac{19}{30}$ June, 1753. In other cases the month was changed as well as the day; thus the day which was the 30th June, 1753, old style, became the 11th July, new style, and the date was written

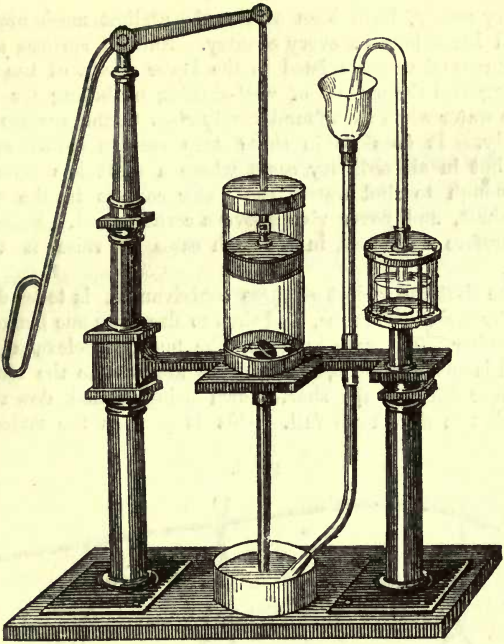
$$\frac{\text{30th June,}}{\text{11th July,}}\ 1753.$$

In other cases again, the day, month, and year were all changed, as, for example, the day which, in the old style, was the 23rd February, 1753, in the old style, became the 6th March, 1754, in the new style, and was thus written :—

$$\frac{\text{23rd February, 1753.}}{\text{6th March, 1754.}}$$

117. The difficulties which such a change at first produced among the great mass of the population of the country, who, from their limited education and information, must have been unaware of the many important grounds on which the reform was based, can be easily conceived.

Happily, however the reform was realised, and the inconveniences which first attended it disappeared after a few years, so that the English dates were not only brought into accordance with the course of the seasons, but with those adopted by other civilised nations.



FORCING PUMP

COMMON THINGS.

PUMPS.

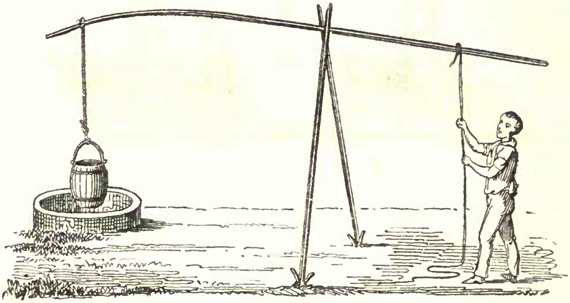
1. Earliest methods of raising water.—2. Bucket in a well.—3. By windlass and rope.—4. By two buckets balanced over a pulley.—5. Method of working these by animal power.—6. The rope in this case balances itself.—7. The lifting pump.—8. Double lifting pump worked by animal power.—9. Various forms of valves.—10. Clack valves.—11. Conical spindle valves.—12. Ball valves.—13. The suction pump.—14. Analysis of its action.—15. Forcing pump.—16. Same with air vessel.—17. Same with solid plunger.—18. Double action forcing pump.—19. Garden watering pumps.—20. Fire-engine.—21. Chain pump.—22. Drainage of mines.

1. As water is one of the most universal necessaries of life, and abundant as it is in nature, is not always found in the localities where circumstances oblige us to fix our habitations, expedients by which it can be obtained in sufficient quantity, and of the

necessary purity, have been among the earliest mechanical and physical inventions in every country. Natural springs showed that sources of water existed in the lower strata of the earth. This suggested the process of well-sinking or boring for water. But the water when thus found rarely rises to the surface spontaneously. It does so in those deep springs called artesian wells; but in all ordinary cases where a shaft has been sunk deep enough to find water, the water collects in the bottom of the shaft, and never rises above a certain level. Expedients are therefore necessary in all such cases to raise it to the surface.

2. The first and rudest of these contrivances, is to let down a bucket by means of a rope, and thus to draw up one bucket-full after another. The rope by which the bucket is elevated, when the well is not very deep, is sometimes attached to the long arm of a lever (fig. 1) the shorter arm being pulled down when the bucket is drawn up full. This is perhaps the rudest and most inartificial of all contrivances for the elevation of the water. A pulley established over the mouth of the well is one degree more efficient.

Fig. 1.



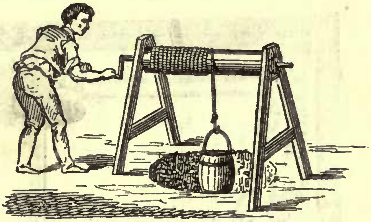
The bucket being let down and dipped in the water, is drawn up by pulling the rope.

In this case the labour is expended not only in raising the weight of the water and of the bucket which contains it, but also that of the rope, which, if the well be deep, is not inconsiderable. Besides this a certain force must be exerted to bend the rope continually over the groove of the pulley, and to overcome the friction of the pulley itself in moving upon its axle.

3. A windlass established over the mouth of the well (fig. 2) is one degree, and only one degree, more efficient than these rude

expedients. In this case the bucket is raised by turning the winch of the windlass, so that the rope is gradually wound upon its axle. The power has still to raise the weight of the rope, to produce its flexure on the axle, and to overcome the friction of the axle of the windlass in its bearings.

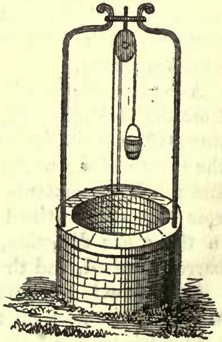
Fig. 2.



In the contrivance of mechanical agents, the first object is always to remove as much as possible all sources by which the moving power is absorbed upon useless objects. In the present case the only useful exertion of the moving force is that which is engaged in raising the water. The useless parts of the force expended, are, *first*, that absorbed by the weight of the bucket; *secondly*, that absorbed by the weight of the rope; *thirdly*, that absorbed in bending the rope over the groove of the pulley, or the curvature of the axle; *fourthly*, that which is expended on the friction of the axle in its bearings; *fifthly*, that which is expended in drawing the bucket aside when it has been elevated, and discharging the water from it into the vessel or reservoir destined to receive it; and, *sixthly*, that which is expended in letting down the bucket into the well to be refilled.

Now when all these sources of waste of power are considered and estimated, and their aggregate amount determined, it will be apparent that they greatly exceed the force expended upon the mere elevation of the water.

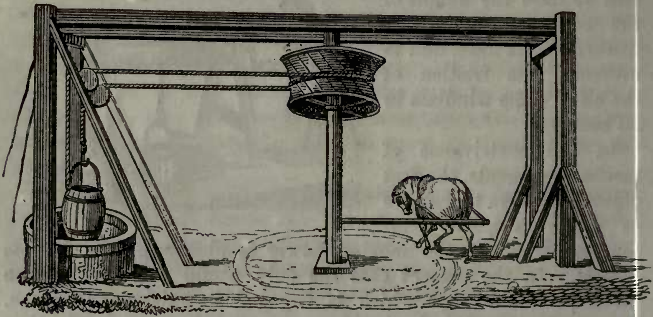
Fig. 3.



4. A part of the loss of power arising from these causes is sometimes removed by the simple expedient of attaching two buckets to the extremities of the rope which passes over the pulley (fig. 3) established above the well. By these means, while the full bucket is drawn up the empty one descends, and by its weight and that of the rope which descends with it, the weight of the full bucket and the rope which ascends with it is balanced, so that the power has only to act against the weight of the water, the friction and the resistance to flexure presented by the rope.

5. Animal power may be applied to this method of raising water by such an arrangement as is represented in fig. 4. This is the method generally used in France by the market gardeners, in the environs of large towns, to raise water for irrigation. Two pulleys are established side by side, over the well, at such a distance asunder that two buckets or barrels suspended from them may pass each other as one ascends and the other descends, without mutual collision or obstruction. The rope supporting one bucket, after passing over one of these pulleys, is carried two or three times round a large vertical drum erected near the well, and then passing over the other pulley is let down into the well with the other bucket attached to it.

Fig. 4.



The semicircular handles to which the rope is attached, are connected with the barrels, not at the edge of the mouth, but at two points in their sides, a little above their middle point, so that when filled they will maintain themselves steadily in the vertical position, but when empty they will easily be turned upon their sides by mere contact with the surface of the water so as to fill themselves, when let down empty.

A horse or ox yoked to a lever of considerable length, projecting from the vertical shaft, turns it, and with it the drum, and continues to go round in the same direction, until one barrel is raised to the mouth of the well and the other is plunged in the water below and filled, the contents of this barrel being discharged into a reservoir or vessel destined to receive it. The animal is then yoked in the other direction, and again travels round until the other barrel is raised, and that which was just discharged let down.

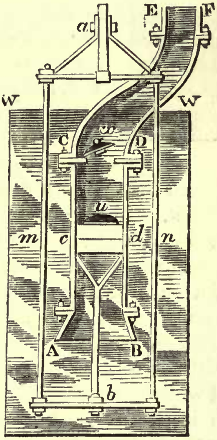
6. It is evident that in this and all similar arrangements the weight of the rope on the whole balances itself; for although it preponderates against the power when the full barrel begins to

ascend, the ascending part of the rope being then longer than the descending, this preponderance gradually decreases until the ascending meets the descending barrel. At this point, the ascending and descending parts of the rope being equal, balance each other, and after this the descending part, preponderating, aids the power just as much as the ascending part previously opposed it. There is, therefore, so far as relates to the weight of the rope, a perfect compensation.

The same apparatus is much used in France, in raising stone through vertical shafts from subterranean quarries, and other mining operations.

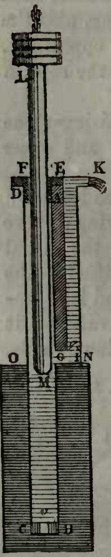
7. If, instead of a rope and bucket, a pipe or tube be let down into the well, and in this pipe a piston be provided, having a valve in it opening upwards, this piston being worked in the usual manner upwards and downwards, the water would be lifted in the pipe. Such an apparatus is called a lifting-pump, and is represented in fig. 5: W is the water, *c d* the piston, *u* the valve in it which opens upwards. When the piston is moved downwards, this valve opens, and the water passes through it. When the piston is moved upwards, the column of water is pushed up, and the valve is kept closed by the pressure of the water upon it. A valve *x* is placed at C D in a fixed position, through which the column of water passes when the piston rises, and which prevents the return of such water downwards, the valve being kept closed by the weight of the water above it. The column of water driven upwards by the piston is pushed to any required height, through the pipe E F. In such an apparatus, the moving power must be equal to the weight of the water raised, together with the weight of the pump-rod and frame by which the piston is worked, as well as the friction of the moving parts.

Fig. 5.



8. A very ingenious form of pump which, though differing altogether in appearance from the lifting pump, acts nevertheless upon precisely the same principle, is shown in fig. 6. It has the advantage of being nearly free from friction, and of being capable of being worked by the weight of an animal walking up an inclined plane, which is the most advantageous manner in which animal power can be applied.

Fig. 6.



Let D C be a wooden tube of any shape, round or square, which descends to a depth in the well or reservoir equal to the height above the surface of the reservoir to which the water is required to be raised. Thus if D O be the height to which the water is to be raised above the level of the well, then the depth O C must be at least equal to D O. L M is a heavy beam or plunger, suspended from a chain, and capable of descending by its own weight in water, and passing water-tight through the collar F E. A valve, *v*, covers an opening placed at the bottom of the tube. By the hydrostatic pressure the water will enter the valve *v*, and fill the barrel to the level O G of the water in the cistern. G I is a short tube proceeding from the side of the barrel, at the surface of the water, and communicating with the vertical tube E N by a valve I, which opens upwards. K is the spout of discharge. The plunger L M hangs loosely in the tube, so that it moves upwards and downwards perfectly free from friction, except that of the collar F E, where it is properly lubricated. When this plunger is allowed to descend by its weight into the water which fills the lower part of the tube, the valve *v* is closed, and the water displaced by the plunger is forced through the valve I into the tube E N. When the plunger is raised the valve I is closed, and the water thus forced into the tube E N cannot return. The water from the cistern then flows through the valve *v*, and rises in the tube to the level G. The next descent of the piston propels more water into the tube E N, and this is continued so long as the piston is worked.

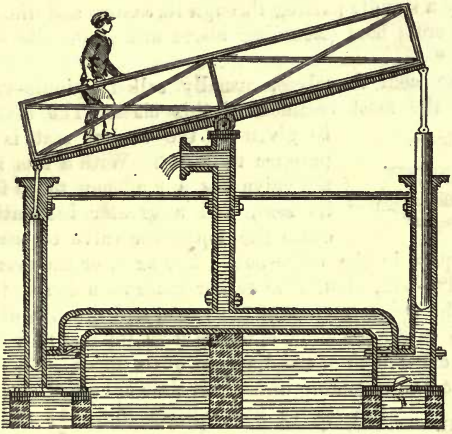
The manner in which such an apparatus is worked by the weight of a man, or any animal, is represented in fig. 7, p. 183. Two pumps are used, such as that just described, and when the plunger descends in one it rises in the other. The two pumps communicate with one vertical pipe, which therefore receives a continual supply of water; for while the action of one pump is suspended the other is in progress. A man walks from one end of an inclined plane to the other, and by his weight upon one side or the other of the fulcrum causes the plungers alternately to rise and fall.

9. Valves are of such constant use in all forms of pump, that it will be useful here briefly to explain their principal varieties.

A valve in general is a contrivance by which water or other fluid flowing through a tube or aperture is allowed free passage in one direction, but is stopped in the other. Its structure is such, that while the pressure of the fluid on one side has a tendency to close it, the pressure on the other side has a tendency to open it.

As in all forms of pump the water is required to be moved upwards, all the valves necessarily open upwards and close downwards.

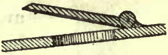
Fig. 7.



There are several varieties of form.

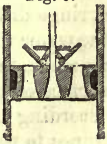
10. The clack valve is like the lid of a box (fig. 8). It opens upwards, playing upon a hinge, and when the water presses it downwards it is closed.

Fig. 8.



The single clack valve is the most simple example of the class. It is usually constructed by attaching to a plate of metal larger than the aperture which the valve is intended to stop, a piece of leather, and to the under side of this leather another piece of metal smaller than the aperture. The leather extending on one side beyond the larger metallic plate, and being flexible, forms the hinge on which the valve plays. Such a valve is usually closed by its own weight, and opened by the pressure of the fluid which passes through it. It is also held closed more firmly by the pressure of the fluid whose return it is intended to obstruct.

Fig. 9.



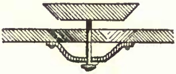
The extent to which such a valve should be capable of opening, ought to be such that the aperture produced by it shall be equal to the aperture which it stops. This will be effected if the angle through which it rises be about 30°.

A double clack consists of two semicircular plates, having the hinges on the diameters of the semicircles, as represented in fig. 9.

Of the valves which are opened by a motion perpendicular to their seat, the most simple is a flat metallic plate, made larger than the orifice which it is intended to stop, and ground so as to rest in water-tight contact with the surface surrounding the aperture. Such a valve is usually guided in its perpendicular motion by a spindle passing through its centre, and sliding in holes made in cross bars extending above and below the seat of the valve.

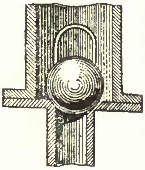
11. The conical valves, usually called spindle-valves (fig. 10), are the most common of this class. The best angle to be given to the conical seat is found in practice to be 45°. With a less inclination the valve has a tendency to be fastened in its seat, and a greater inclination would cause the top of the valve to occupy unnecessary space in the valve-box. The area, or transverse section of the valve-box, should be rather more than double the magnitude of the upper surface of the valve, and the play of the valve should be such as to allow it to rise from its seat to a height not less than one-fourth of the diameter of its upper surface.

Fig. 10.



12. The valves coming under this class are sometimes formed as spheres or hemispheres (fig. 11) resting in a conical seat, and in such cases they are generally closed by their own weight, and opened by the pressure of the fluid which passes through them.

Fig. 11.

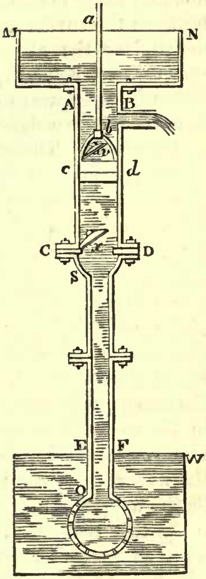


13. The several expedients already described are, however, greatly surpassed in convenience by the form of pump almost universally used in domestic and general economy, and known as the sucking or suction pump.

A section of this useful apparatus is shown in fig. 12, p. 169. It consists of a pipe or barrel, S O, which descends into the well, and the length of which must not exceed 32 feet. Attached to the top of this pipe, which is called the suction-pipe, is a large syringe, acting precisely on the principle of a common exhausting syringe.

At the commencement of the operation, the pipe S E is filled with air to the level of the water in the well. The operation of the syringe draws the chief part of the air out of this pipe S E. When the water within the pipe is partially relieved from the atmospheric pressure, the weight of the atmosphere, acting upon the external surface of the water in the well, forces it up in the pipe S E; and according as the air is withdrawn by the syringe, the water continues to rise, until it passes through the valve *x*. This valve opening upwards, prevents its return, since the weight of the column above it will keep it closed. When the barrel A C becomes filled with water, the syringe no longer acts as such, but works on the principle of the lifting pump, already explained. When the piston descends, the valve x is closed and the valve v opened, the water passing through the piston. When the piston is raised, the valve v is closed, and the column of water above the piston is projected upwards.

Fig. 12.



Meanwhile the pressure of the atmosphere on the water in the well causes more water to rise in the pump-barrel following the piston.

The atmospheric pressure is capable of supporting a column of about 34 feet of water.* It is evident, therefore, that such a pump as is here described can only be efficient when the piston is at a height of less than 34 feet above the surface of the water in the well, since otherwise the atmospheric pressure would not keep the water in contact with the piston.

The suction-pump, therefore, as compared with the lifting-pump, saves 34 feet length of pump rod; but otherwise there is no comparative mechanical advantage.

It might appear at first view that the pressure of the atmosphere sustaining a column of water in the suction-pipe, supplies aid to the power that works the pump, and spares an equivalent amount of that power.

This, however, is not the case, as will appear from a due consideration of all the forces which are in operation.

14. Of these forces there are some which are directed downwards from the top of the column raised by the piston towards the bottom of the well, and others which are directed upwards. Now it is evident that the mechanical power applied to draw the piston up will have to overcome all that excess by which the forces downwards exceed the forces upwards. Let us suppose a column of water resting on the piston, after having passed through the valve v. The upper surface of this column is pressed upon by the weight of the atmosphere; the piston has, therefore, this

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* See Tract on Barometer (10).

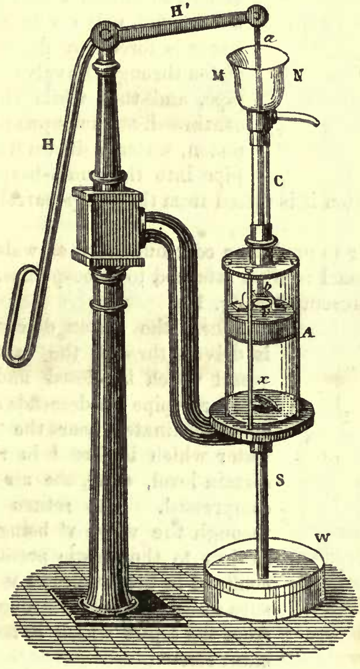
weight to sustain. It has also to sustain the weight of the water which is above it. The atmospheric pressure acting also on the water in the well, is transmitted by the water to the bottom of the piston; but this effect is diminished by the weight of the column of water between the surface of the water in the well and the bottom of the piston, for the atmospheric pressure must, in the first place, sustain that column, and can only act upon the bottom of the piston in the upward direction with that amount of force by which it exceeds the weight of the column of water between the piston and the well. The effect, therefore, on the piston is the same as if it were pressed downwards by the weight of the column of water between the piston and the well, and at the same time pressed upwards by the atmospheric pressure. Thus the piston may, in fact, be regarded as being urged downwards by the following forces,—the atmospheric pressure, the weight of the water above the piston, and the weight of the water between the piston and the well; that is to say, in fact, by the atmospheric pressure, together with the weight of all the water which has been raised from the well. At the same time, it is pressed upwards by the atmospheric pressure transmitted from the surface of the water in the well. This upward pressure will destroy the effect of the same atmospheric pressure acting downwards on the surface of the water above the piston, and the effective downward force will be the weight of all the water which is contained in the pump.

By this reasoning, it appears that the pump must be worked with as much force as is equal to the weight of all the water which is in it at any time, and, therefore, that the atmospheric pressure affords no aid to the working power.

Since the action of the pump in raising water is subject to intermission, the stream discharged from the spout will necessarily flow by fits and irregularly, if some means be not adopted to prevent this. At the top of the pump a cistern may be constructed, as shown in fig. 12, with a view to remove this inconvenience. If the pump be worked, in the first instance, so as to raise more water in a given time than is discharged at the spout, the column of water will necessarily accumulate in the barrel of the pump above the spout. The cistern M N will, therefore, be filled, and this will continue until the elevation of the surface of the water in the cistern above the spout will produce such a pressure, that the velocity of discharge from the spout will be equal to the velocity with which the water is raised by the piston. The level of the water in the cistern will therefore cease to rise. This level, however, will be subject to a small variation as the piston rises; for while the piston is descending, the water is flowing from the spout, and no water is raised by the piston, consequently the level of the water in the cistern falls. When the piston rises, water is raised, and the quantity in the cistern is increased faster than it flows from the spout, consequently the level of the water in the cistern rises, and thus this level alternately rises and falls with the piston. But if the magnitude of the cistern be much greater than the section of the pump-barrel, then this variation in the surface will be proportionally small, for the quantity of water which fills a part of the barrel, equal to the play of the piston, will produce a very slight change in the surface of the water in the cistern. The flow, therefore, from the spout will be uniform, or nearly so.

The action of this sort of pump will be rendered still more easily intelligible by fig. 13, which represents the working model of a

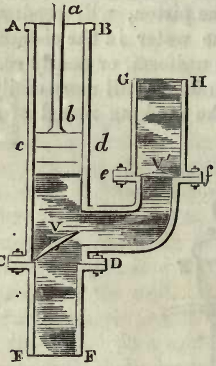
Fig. 13.



suction-pump usually provided for demonstrations in popular lectures. The pump-handle H H′ raises and lowers the piston rod *a*. The pump-barrel is formed of glass, so as to show the piston within it, having a valve opening upwards. The other parts of the apparatus are marked with letters corresponding with those of fig. 12.

15. Another form of pump, called the forcing-pump, is attended with many advantages, and is extensively used. This instrument is represented in fig. 14. The suction-pipe C E is similar to the suction-pump. The piston *c d* is a solid plug without a valve.

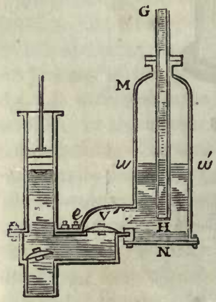
Fig. 14.



The forcing-pipe G H has at its base *e f* a valve V′ which opens upwards. When the piston *c d* is raised, the valve V is opened, and the water rises from the suction-pipe into the pump-barrel. When the piston *c d* is pressed downwards, the valve V is closed, and the water is forced by the pressure of the piston through the valve V′ into the force-pipe, and thus while the operation is continued, at each upward motion of the piston, water is drawn from the suction-pipe into the pump-barrel, and at each downward motion it is forced from the pump-barrel into the force-pipe.

16. In order to produce a continued flow of water in the force-pipe, an air-vessel is often attached to force-pumps. Such an appendage is represented in fig. 15.

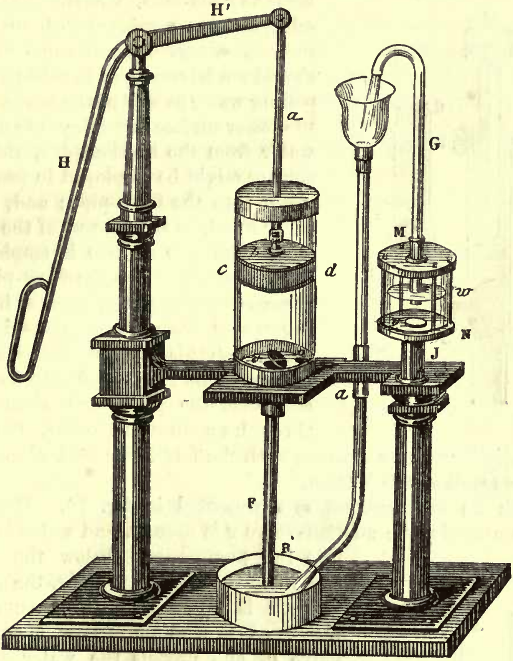
Fig. 15.



When the piston descends, the water is driven through the valve V′ into the vessel which is closed and contains air. The force-pipe G H descends into this vessel, and terminates near the bottom. The water which is forced in rises in it to a certain level, *w w′*, the air above it being compressed. The return of the water through the valve V′ being stopped, it is subject to the elastic pressure of the air confined in the air-vessel M N. This pressure forces the water through the tube H G from the top of which it issues in a constant stream.

The forcing-pump with its air-vessel, as constructed for demonstration at popular lectures, is shown in fig. 16, p. 189, where all the parts are indicated by the same letters as in figs. 14 and 15. The water which flows in a continual stream from the force-pipe G returns by the pipe P to the reservoir R, from which it is again raised by the pump.

Fig. 16.

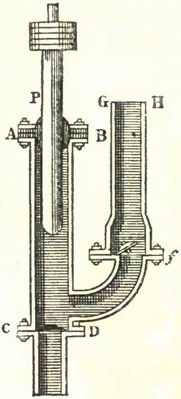


17. In the force-pump, where the water acts upon the piston with a great pressure, it is very important that the piston should move in complete water-tight contact with the pump-barrel. This is best accomplished by an accurately formed metallic plunger, P, fig. 17, working through a collar of leather, A B, which is exactly fitted to it, and with which it is made air-tight and water-tight, by being lubricated with oil or tallow. When this plunger is raised, the space it deserts is filled by the water which rises through the valve V, and when it descends, the water which filled the space into which it advances, is driven before it through the valve V into the force-pipe.

18. If the forcing-pump, represented in fig. 16, be attentively considered, it will be perceived that the principles on which the piston acts, in its ascent and descent, are perfectly distinct. In

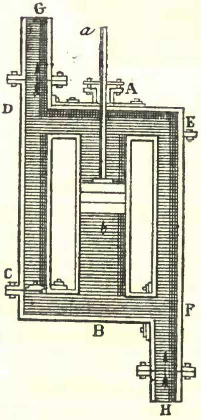
its ascent it is employed in drawing the water from the suction-pipe into the pump-barrel, and in its descent it is employed in forcing that water from the pump-barrel into the force-pipe. Now the piston being solid, and not furnished with any valve, there is no reason why its upper surface should not be employed in raising or propelling water as well as the lower. While the lower surface is employed in drawing water from the suction-pipe, the upper surface might be employed in propelling water into the force-pipe; and, on the other hand, in the descent of the piston, when the lower surface is employed in propelling water into the force-pipe, the upper surface might be engaged in drawing water from the suction-pipe. To accomplish this, it is only necessary that the top of the cylinder should be closed, and that the piston-rod should play through an air-tight collar, the top of the cylinder communicating with the force-pipe and the suction-pipe, as well as the bottom.

Fig. 17.



Such an arrangement is represented in fig. 18. When the piston ascends, the suction-valve F is opened, and water is drawn into the pump-barrel below the piston; and when the piston descends, the suction-valve F is closed, and the pressure of the piston on the water below it opens the valve C, and propels the water into the force-pipe C G. Also, while the piston is descending, water rises through the suction-valve E into the barrel above the piston; and when the piston ascends, the water being pressed upwards keeps the valve E closed, and opens the valve D, and is thus propelled into the force-pipe. By this arrangement the force-pipe receives a continual supply of water from the pump-barrel without any intermission; and in like manner the pump-barrel receives an unremitting flow from the suction-pipe. This will be distinctly seen, if it is considered that either of the two valves E or F must always be open. If the piston go down E is open and F

Fig. 18.



closed; if it go up E is closed and F open. A stream, therefore, continually flows through one valve or the other into the pump-barrel. In like manner, whether the piston ascend or descend, one of the valves, C or D, must be open.

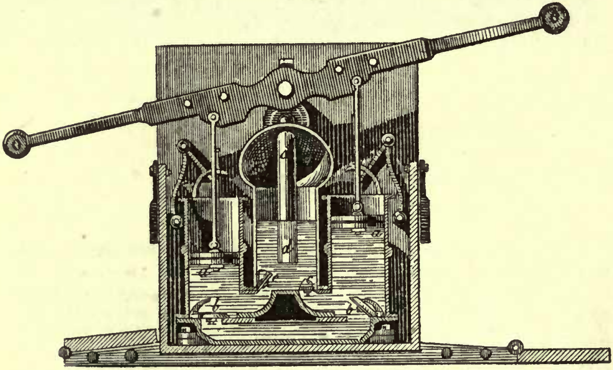
19. The simple pumps used for watering gardens are shown in fig. 19, at the head of this tract, a single or double-action force-pump projecting a jet of water over the ground to be irrigated.

20. The fire-engine is a double forcing-pump, each barrel of which acts upon the principle explained above.

A section of such an engine, in its most usual form, is represented in fig. 20.

The solid pistons *a a* are alternately forced down upon the water which has been drawn into the barrels upon the principles already explained, and the water is thus forced into the air vessel *e*. The reaction of the compressed air drives the water with a proportionate force through the force-pipe *d* into a long, flexible, leathern hose, upon the end of which a large jet-pipe is screwed. The firemen carry this jet-pipe near to or into the building on fire, and with it throw up to great heights a constant stream of water, which, falling on the burning bodies, extinguishes the fire.

Fig. 20.



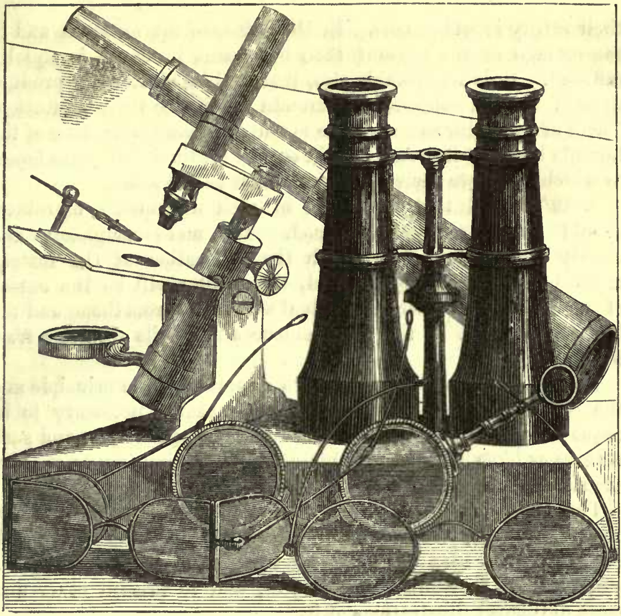
21. A form of lifting-pump, called the chain-pump, is commonly used to discharge the water from the hold of ships of war and other vessels of the large class. This pump consists of an endless chain which passes over two rollers, one of which is established on the deck, above the level at which the water is to be discharged, and the other at the bottom of the hold. Attached to the chain, and placed at right angles with it, are a series of saucers, or a sort

of flat circular plates, one above the other, by which the water is lifted. These saucers lift the water and press it up through a vertical pipe placed near the ascending side of the chain. The water, rising through this pipe, is discharged into a cistern on the deck, from which it flows off into the sea through a waste pipe called the *pump-dale.*

There are two hollow vertical barrels, or cases, through one of which the chain ascends, and through the other it descends. The chain is worked by means of a winch attached to the upper roller, over which it passes. This winch receives a continual motion of rotation, by the power of men applied to its handles, which are so formed that several men can work them simultaneously.

In large vessels these pumps are constructed upon a scale sufficient to enable them to raise a ton of water, or about 250 gallons per minute.

22. The purpose to which pumps are applied on the most vast scale is in the drainage of mines. In that case the power required far exceeds the limit to which animal power is practically available, and even steam-power, by which such pumps are worked, requires to be applied on a scale far exceeding every other form in which it has been applied in the industrial arts.



COMMON THINGS.

SPECTACLES.

1. Their general utility.—2. Should therefore be generally understood.—3. Vision.—4. Blindness.—5. Defective sight.—6. Long and short sight.—7. Remedy.—8. Spectacles.—9. Effect of convex lenses.—10. Of concave lenses.—11. Focal length of a lens.—12. Varies with distance of object.—13. Peculiarities of vision in short sight explained.—14. In long sight.—15. The mounting of spectacles.—16. Periscopic spectacles.—17. Both eyes have not always the same power of vision.—18. Ophthalmometer.—19. Application of it in selecting glasses.—20. Curious defects of vision.

1. Spectacles are incontestably the most universally useful gift which optical science has conferred on mankind. More wonderful instruments abound. The miracles disclosed to human vision by the telescope and the microscope are known to all. To such marvels, spectacles lay no claim. But to compensate for this

their utility is ubiquitous. In the palace of the monarch and in the cottage of the peasant their beneficent influence is equally diffused. It is remarkable also, that, unlike most other productions of art and science, cost can add nothing to their perfection. Those of the millionaire may be mounted in gold, and those of the humble labourer in iron; but the optical medium, the glass lenses to which they owe their perfection, must be the same.

2. It is good that an object of such unbounded usefulness should be generally understood. The more completely and clearly the principles on which the application of the instrument depends are comprehended, the greater will be the extent of the benefit which each individual will derive from them, and the less frequent will be the inconveniences and evils resulting from their abuse.

Before it is possible, however, to comprehend the principle and the right use of spectacles, it is indispensably necessary to be acquainted with the structure and functions of the eyes, and such readers as have not already obtained that preliminary knowledge are referred for it to our tract on that subject.

The defects incidental to the sense of sight have been briefly noticed in that tract, and the optical expedients by which remedies have been obtained for them have been stated. We propose here to resume that subject, and to present other and more developed illustrations of it.

3. When an object is placed at a certain distance from the eye, a small picture or image, as it is called, of the object is produced upon the posterior surface of the coating which lines the inside of the spherical shell, called the eye-ball. This coating, upon which the picture is thus formed, is called the retina.

It is this picture on the retina which enables us to see the object. If this picture be obscure, falsely coloured, confused, or indistinct, our vision of the object will also be obscure, falsely coloured, confused, or indistinct.

In its natural and healthy state the structure of the eye is such that the pictures of all objects presented to it thus formed upon the retina, are clear, rightly coloured, and perfectly distinct in form and outline. In individual cases, however, eyes are variously defective.

4. If the coats and humours, through which the rays of light, proceeding from external objects ought to pass, be not in any degree transparent, no picture whatever is formed on the retina, and the subject is blind.

5. If the coats and humours are imperfectly transparent the picture will be obscure, being formed only by the rays of light partially transmitted through the humours.

It sometimes happens that the humours, like coloured glass or coloured liquids, transmit only light of a particular colour. In that case the image on the retina is falsely coloured, the false colours depending on the colour of the humours.

For these several classes of defects spectacles are wholly inefficacious.

6. When the humours are perfectly transparent and free from colour, the picture which they would produce may fall not immediately upon the retina, but at a distance more or less considerable before or behind it. In that case the effect produced upon the retina will be a picture more or less confused and indistinct. It will be so much the more indistinct as the place where the distinct picture would be formed is more distant from the retina.

If the place of the distinct picture be before the retina, the defect is owing to the eye having too great refracting power upon the rays of light. If it be behind the retina, it is owing to the refracting power being too feeble.

The former is called SHORT SIGHT, and the latter LONG SIGHT, or WEAK SIGHT.

7. For these defects of vision, which are by far the most common, spectacles supply a perfect remedy.

They accomplish this by the effect they are capable of producing upon the place of the picture. If the eyes be weak-sighted, and consequently the picture is formed *behind* the retina, spectacles are applied which have the effect of bringing forward the picture to the retina. If they be short-sighted, so that the picture is formed *before* the retina, spectacles are applied which have the effect of throwing it back to the retina.

8. Spectacles consist of circular discs of glass called lenses, the surfaces of which are brought by grinding and polishing to a convex or concave form.

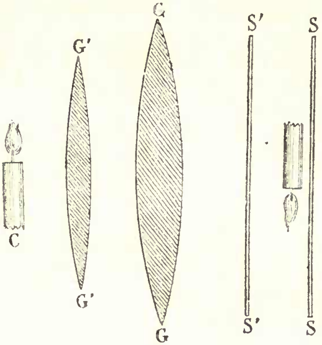
9. If a convex lens of this kind be placed before the eye, it will have the effect of bringing forward the picture formed within the eye. A concave lens, placed in the same manner, will have the contrary effect of throwing it backward.

It will be easy for any person to convince themselves that such glasses have the properties here described.

Let a convex disc of glass or lens, G G, fig. 1, be placed before a candle, C, and let a white paper screen be placed behind G G, and moved towards and from it until a position is found, such as S S, in which a distinct inverted picture of the candle will be seen upon it. If the screen be now moved to S′ S′, a little nearer to G G, so that the place of the distinct picture shall be *behind* it, an indistinct picture of the candle will be seen upon the screen.

In this case the lens G G may be imagined to represent the eye of a weak-sighted person, the candle c a visible object, and the screen s′ s′ the retina, upon which an indistinct image of the object

Fig. 1.



s depicted, and s s the place behind the retina, at which the picture would be distinct.

Now if another convex lens, g′ g′, which may represent a spectacle glass, be placed before g g, it will have the effect of bringing forward the place of the distinct image, and it will bring that place more or less forward according as g′ g′ is more or less convex. It is easy to conceive that its convexity may be such that the image of the candle will be brought exactly to the position of the screen s′ s′.

Thus it appears, that if the screen be misplaced, with relation to the distinct picture of the candle, so as to be before it, a glass g′ g′ of suitable convexity, placed before g g, will bring the distinct picture forward to the position of the screen, upon which it will then be seen.

This is a simple experiment which any one can try with a candle, a sheet of paper, and two spectacle glasses.

It perfectly represents the case of a weak-sighted person, and the benefit they derive from convex spectacle glasses.

If, however, the lens g′ g′ be too convex, the picture will be brought too much forward, and it will be formed not on the screen s′ s′, but before it, and will consequently be indistinct. If, on the contrary, the lens g′ g′ be not sufficiently convex, the picture will not be brought so forward as the screen s′ s′, and will still be indistinct upon it.

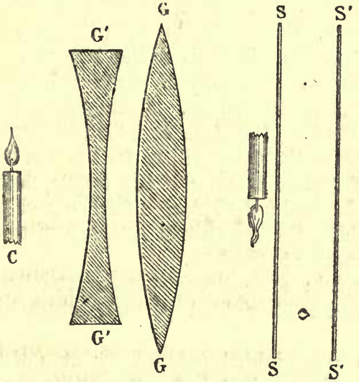
Thus, between the relative positions of the distinct picture of the candle, that of the screen s′ s′, and the convexity of the lens

G′ G′, there is a certain relation, such that only one particular degree of convexity will bring the distinct picture upon the screen.

In the same manner, it follows that between the relative positions of the retina, of the distinct picture formed behind it, and the convexity of the spectacle glasses, there is a certain fixed relation, such that such glasses only as have a particular convexity will bring the distinct picture on the retina, and produce clear and distinct vision.

10. Let us suppose now that the screen is placed as at S′ S′, fig. 2, *behind* the position at which the distinct picture of the candle is formed. In this case it is required to throw the distinct picture *backwards*, and as it was brought forwards by the interposition of a *convex* glass, it will be thrown *backwards* by the interposition of a *concave* glass. Such a lens, G′ G′, having the proper degree of concavity, being therefore placed before G G, the distinct image will be seen upon the screen S′ S′.

Fig. 2.



As in the former case, there is a certain relation between the relative positions of the distinct picture of the candle, of the screen S′ S′, and the concavity of the lens G′ G′, so that only one particular degree of concavity will throw back the distinct picture to the screen.

As in the former case, this experiment illustrates the case of a short-sighted eye, and the remedy affixed by the interposition of a concave glass. The lens G G represents the eye, S′ S′, the retina, and S S the place before it where the distinct picture is formed when no glass is used. When G′ G′ is interposed between the object and the eye, the distinct image is thrown back to S′ S′, the place of the retina.

11. The place at which the distinct image of a distant object is formed by a lens, or by any other optical medium equivalent to a lens, is called the FOCUS of the lens, and the distance of the focus from the lens is called the FOCAL LENGTH of the lens.

When the structure of the eye is perfect, therefore, its focus must be on the retina, and its focal length will be the interior diameter of the eye-ball. When the focal length of the eye is greater than this the focus is behind the retina, and the eye is weak-sighted or long-sighted. When the focal length is less, the focus is before the retina, and the eye is short-sighted.

12. If an object, a candle for example, placed before a convex lens, be moved towards the lens, the place at which its distinct picture is formed, that is its focus, will move from the lens, so that the nearer the object is to the lens the further will its picture be from it. It is easy to verify this by means of the candle, the lens, and the screen. As the candle is moved nearer and nearer to the lens, the place at which the screen will receive a distinct picture of the flame will be farther and farther from the lens, and in the same manner if the candle, being placed very near the lens, be gradually removed farther and farther from it, the place at which the screen will receive a distinct picture will be nearer and nearer to the lens.

This will explain some circumstances attending the vision of near-sighted and weak-sighted persons, which are familiar to every one.

13. When a near-sighted person looks at a distant object, its focus is within the eye-ball, before the retina, on which, consequently, the picture is indistinct. But if the object be brought gradually nearer and nearer to the eye, its distinct picture will move more and more backward, according to what has been just shown, and it will consequently approach nearer and nearer to the retina, until at length the object is brought so near the eye, that the distinct picture exactly falls upon the retina. The vision is then perfect.

It will thus be understood why near-sighted persons can see objects distinctly, only when they are brought within a certain distance of the eye. The more removed the focus of their eye is from the posterior part, the nearer an object must be brought before the picture is thrown back to the retina, and the person is said to be so much the more near-sighted.

Concave spectacle-glasses, in this case, have the same effect in throwing back the picture as the proximity of the object, and with such spectacles the object can consequently be seen distinctly without being brought near to the eyes. If, when the spectacles are interposed, the object be brought as near the eyes as would be necessary for distinct vision without spectacles, the vision will be indistinct; because, in that case, the effect of the glasses will be to throw the distinct picture behind the retina, which, without the glasses, would have been upon it.

When persons are not very short-sighted, they generally read or work without spectacles, but require their aid when they walk abroad or move in society in large rooms, because the book or the objects of their work can, without inconvenience, be placed at the moderate distance from their eyes which is sufficient to throw the focus back upon the retina, but the more distant objects at which they look when walking abroad or in large rooms are beyond the proper limit of distance, and the focus, being before the retina, must be thrown back by concave spectacles.

14. When an object is placed near the eyes of a weak-sighted person, the focus is behind the retina, and the picture on the retina is consequently indistinct. If the object be gradually removed to a greater and greater distance, the focus, according to what has been explained, will approach the retina nearer and nearer, and, if the sight be not too weak, it will come upon the retina when the object is removed to a certain distance from the eye. In this case, however, owing to the greater distance of the object, stronger illumination is required, and it is found, accordingly, that when weak-sighted persons hold a book at arms-length from the eyes, they are obliged, at the same time, to place a strong light near the page.

Eyes, which are not of very weak sight, have sufficient power to bring the picture of all objects, whose distance exceeds three or four feet, upon the retina. But for nearer objects, the picture, being behind the retina, requires to be brought forward by the interposition of convex spectacles. The nearer the object looked at is, the more convex ought the glasses to be, and hence it comes that very weak-sighted persons require to be provided with more than one pair of spectacles, those adapted to more distant objects being less convex, and those adapted to nearer objects more so.

When the weakness of sight is so limited that the pictures of distant objects fall upon the retina, those only of nearer ones being behind it, the eye is said to be FAR-SIGHTED, in contradistinction to the opposite defect, by which distinct vision is only obtained by the closer proximity of the object.

15. Spectacles consist of two glass lenses mounted in a frame so as to be conveniently supported before the eyes, and to remedy the defects of vision of naturally imperfect eyes.

Whatever be the defects of sight which they may be used to remove, it is evident that the lenses ought to be so mounted that their axes shall be parallel, and that their centres shall coincide with the centres of the pupils when the optical axes are directed perpendicular to the general plane of the face, that is to say, when the eyes look straight forward.

These conditions, though important, are rarely attended to in the choice of spectacles. If spectacles be mounted in extremely light and flexible frames, the lenses almost invariably lose their parallelism, and their axes not only cease to be parallel, but are frequently in different planes. Spectacles ought therefore to be constructed with mounting sufficiently strong to prevent this derangement of the axes of the lenses, and in their original construction care should be taken that the axes of the lenses be truly parallel.

In the adaptation of spectacles it is necessary that the distance between the centres of the lenses should be precisely equal to the distance between the centres of the pupils. The clearest vision being obtained by looking through the centres of the lenses, the eyes have a constant tendency to look in that direction. Now if the distance between the centres of the lenses be greater than the distance between the centres of the pupils, the eyes having a tendency to look through the centres of the lenses, their axes will cease to be parallel, and will diverge as in the case of an outsquint. On the other hand, if the distance between the centres of the lenses be less than the distance between the centres of the pupils, there will, for a like reason, be a tendency to produce an insquint.

I have myself known persons of defective sight, who had never been able to suit themselves with spectacles, and concluded that they had some defect which spectacles could not remedy. Upon observing the form of their heads, I found, in each case, that the eyes were more distant asunder than eyes generally are, while the spectacles they used, being those made with the lenses at the usual distance, were never, and never could be, so placed as to be concentrical with the eyes, and hence arose the discomfort attending their use. In all such cases I removed the inconvenience by measuring the distance between the centres of the eyes, and causing proper glasses to be mounted in frames, so that the distance between their centres should correspond with the distance between the centres of the eyes.

I would therefore advise every one who uses spectacles to cause the distance between the centres of their eyes to be exactly measured, and to select for their spectacles mountings corresponding with this distance.

16. The most perfect vision with spectacles is produced when the eye looks in the direction of the axis of the lenses, and more or less imperfection always attends oblique vision through them. Persons who use spectacles, therefore, generally turn the head, when those whose sight does not require such aid merely turn the eye.

To diminish this inconvenience, the late Dr. Wollaston suggested the use of menisci, or concavo-convex lenses, instead of double concave or double convex lenses with equal radii, which up to that time had been invariably used.

Sections of lenses of this kind are given in figs. 3 and 4. In fig. 3, the convexity A′ B′ C′, of which the centre is O′, is greater than the concavity A B C, of which the centre is O, and the effect of the lens is the same as that of a convex lens. Such glasses are therefore adapted for weak sight. In fig. 4, on the contrary, the concavity A B C, of which the centre is O, is greater than the convexity A′ B′ C′, of which the centre is O′, and the effect of the lens is the same as that of a concave glass. Such glasses are therefore adapted to short sight.

Fig. 3.

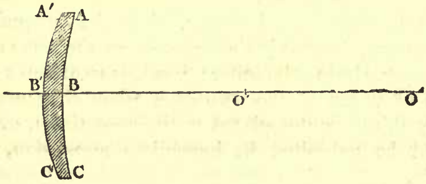
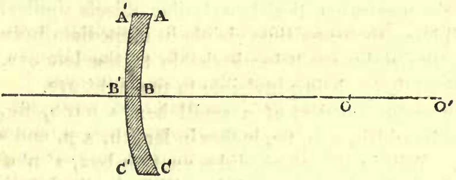


Fig. 4.



The effect of these, as compared with double convex and double concave glasses, is, that objects seen obliquely through them are less distorted and, consequently, that there is a greater freedom of vision by turning the eye without turning the head, from which property they were named *periscopic spectacles*.

17. In the selection and adaptation of spectacles, it is invariably assumed without question, that the two eyes in the same indi-

vidual have exactly the same refracting power. That this is the case is evident, from the fact that the lenses provided in the same spectacles have invariably the same focal length.

Now although it is generally true that the two eyes in the same individual have the same refractive power, it is not invariably so; and if it be not, it is evident that lenses of equal focal length cannot be at once adapted to both eyes.

When the difference of the refractive power of the two eyes is not great (which is generally the case when a difference exists at all), this inequality is not perceived. By an instinctive act of the mind, of which we are unconscious, the perception obtained by the more perfect of the two eyes in case of inequality is that to which our attention is directed, the impression on the more defective eye not being perceived.

It might be expected, however, that the inequality would become apparent, by looking alternately at the same object with each of the eyes, closing the other; but it is so difficult to compare the powers of vision of the two eyes when they are not very unequal, by objects contemplated at different times, even though they should be exhibited in immediate succession, that this method fails.

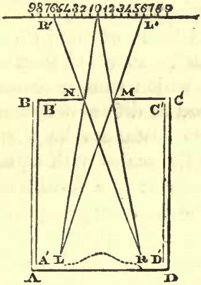
18. My attention having been directed to this question, I contrived an apparatus, which may not inaptly be called an *Ophthalmometer*, by which the least difference in the powers of vision of the two eyes may be rendered immediately apparent.

The principle I adopted for this purpose, resembles that which has been otherwise applied with success in photometers. I have so arranged the apparatus, that two similar objects similarly illuminated shall be at the same time visible in immediate juxtaposition, the one by the right eye being invisible to the left eye, and the other by the left eye being invisible to the right eye.

This apparatus consists of a small box, A B C D, fig. 5, about five inches in width, A D, ten inches in length, A B, and six inches in height. Within this there slides another box, A′ B′ C′ D′, made nearly to fit it, but to move freely within it, the interior of this box being blackened, or lined with black velvet. In the end, B′ C′, is a rectangular aperture, the length of which M N is about an inch, and the height about half an inch; the length, however, being capable of being augmented and diminished by slides. Opposite to the end of the box B C is a white screen, on which is traced a horizontal line parallel and opposite to the opening M N, and marked with a divided scale, the 0 of which is opposite to the centre of the aperture M N, and the divisions upon which are numbered in each direction from 0 by 1, 2, 3, 4, 5, 6. . . . .

Let us suppose the eyes now applied at R and L. Let the sliding interior box B′ C′ be moved until, on closing the left eye, the division 0 of the scale coincides with the edge M of the opening, and at the same time, by closing the right eye, the same division 0 of the scale coincides with the edge N of the opening.

Fig. 5.



It will be always possible to make this adjustment, provided the eyes are placed centrally opposite the opening M N, which may be easily managed by cutting in the edge of the box A D an opening to receive the bridge of the nose. This arrangement being made, it is clear that if we close the left eye we shall see the space upon the scale included by the lines R N and R M continued to the screen R′ L′. Let us suppose this space to include the six divisions of the scale from 0 to 6. If we close the right eye, we shall see with the left eye the six divisions of the scale to the right of 0. Now if we open both eyes and look steadily with them through the aperture M N, giving no more attention to the impression on the one than on the other, we shall see the twelve divisions of the scale, six to the right and six to the left of 0; the six divisions to the left of 0 being seen only with the right eye, and the six divisions to the right of 0 being seen only with the left eye.

In this way we have two similar objects, similarly illuminated and of equal magnitude, in immediate juxtaposition, the one seen by the right and the other by the left eye; and any difference in their distinctness, quality, brilliancy, or colour, will be as clearly and instantly perceivable as the comparative brilliancy of spaces illuminated by two different lights in the photometer. I have already experimented with this apparatus upon my own eyes, the result of which is, that I find that the sight of the right eye is much better than that of the left, the figures to the left of 0 being always more distinct than those to the right of it: but, what is more remarkable, I find that the transparency of the humours of the right eye is more perfect than that of the humours of the left eye, for the space to the right of 0 always appears less bright than the space to the left of it.

19. To apply this instrument for the purpose of adapting spectacle lenses to eyes of unequal powers of vision, it is necessary first to ascertain the existence of the inequality of power in the manner already explained. It would then be necessary to provide two distinct screens on which similar scales might be drawn, so that they might be placed at different distances from the aperture M N. Let their relative distances be then determined, so that the two eyes would see the scales with equal distinctness. These distances will then represent the focal lengths of the divergent lenses which it would be necessary to provide for the eyes, so as to make them see different objects with equal distinctness.

In the case of weak-sighted eyes, this method will not be applicable. In that case let the two screens be placed at equal distances from the aperture M N, and let lenses be selected for each eye separately, closing the other, so as to give a distinct perception of the scales. The two lenses being then simultaneously applied to the eyes, let the scale be viewed with both eyes open. If the lenses be adapted to correct the defect of vision, the two parts of the scale to the right and to the left of 0, seen at the same time by each eye alone, will appear of uniform brilliancy and distinctness.

If defective eyes were tested by this method, I believe it would be found that inequality of vision would be much more common than is generally supposed, and accordingly the adaptation of spectacles would be considerably improved.

20. Cases occur not only in which the comparative powers of vision of the two eyes differ, but in which the power of vision, even of the same eye, is different when estimated in different directions.

I have known short-sighted persons who were more short-sighted for objects taken in a vertical than in a horizontal direction. Thus with them the height of an object would be more perceptible than its breadth, and in general, vertical dimensions more clearly seen than horizontal. This difference arises from the refractive power of the eye taken in vertical planes being different from the refractive power taken in horizontal planes; and the defect is accordingly removed by the use of lenses whose curvatures, measured in their vertical direction, is different from their curvature measured in their horizontal direction. The lenses, in fact, instead of having *spherical* surfaces, have *elliptical* surfaces, the excentricities of which correspond with the variation of the refractive power of the eye.

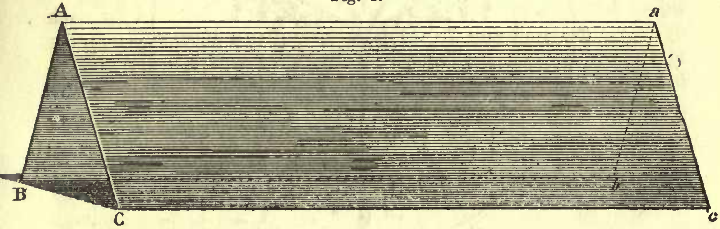
THE KALEIDOSCOPE.

1. Origin of the name.—2. Structure of the instrument.—3. Its optical effect.—4. Varieties of its form.—5. Its occasional use in the arts.—6. Another optical toy depending on two reflections.

1. THIS pretty optical toy, which is named from three Greek words, *καλον εἶδος* (Kalon eidos), *a beautiful form*, and *σκοπεω* (skopeo) *I see*, depends upon the properties of the looking-glass.

2. Two oblong slips of looking-glass, A a c C, and A a b B, fig. 1, are placed edge to edge at A a, inclined to each other at an angle of 60°.

Fig. 1.

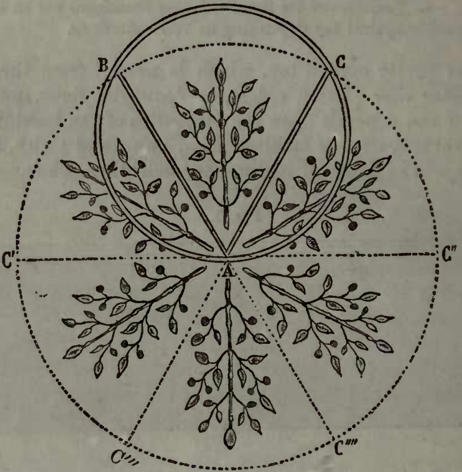


Thus placed, they are fixed in a tube of tin or brass of corresponding size, one end view of which is shown in fig. 2, where the circle A C B represents the tube, and A B and A C the edges of the plates of glass. One end of the tube is covered by two discs of glass, between which broken pieces of coloured glass or other transparent coloured object are placed loosely, so that they can fall from side to side, and take an infinite variety of casual arrangements. The external disc is ground-glass, to prevent the view of external objects disturbing the effect. The other end of the tube is covered by a diaphragm, with a small eye-hole in its centre, through which the observer looks at the coloured objects contained in the cell at the other end. He not only sees these objects, but also their reflection in each of the inclined glasses; and when the angle of inclination is 60°, the object will be seen five times repeated in positions regularly disposed round the line formed by the edges at which the glasses touch each other.

3. The angular space, B A C, included between the glasses, and every object within it, will be seen reflected in each glass. Thus B A C will be seen in the glass B A, as if it were repeated in the

space B A C′, and in the glass A C, as if it were repeated in the space C A C″. But this is not all. The reflection B A C′ becomes an object before the glass A C, and being reflected by it, is reproduced in the space C″ A C'''', and the reflection C A C″ being reflected by the glass A B, is reproduced in the space C′ A C‴. Thus besides

Fig. 2.



the view of the objects themselves which are between the glasses, and which would be seen if there were no reflection, the observer will see the four reflections, two C A C″ and C″ A C'''' to the right, and two B A C′ and C′ A C‴ to the left.

But the reflection C′ A C‴ is again reflected by the glass A C, and is seen in the space C‴ A C'''', and at the same time the reflection C″ A C'''' is reflected in the glass A B, and is also reproduced in the same space C″ A C.″″ Thus it appears that this space C″ A C'''' receives the reflection of both glasses.

The observer looking through the eye-hole of the kaleidoscope sees a circle whose apparent diameter C C‴ is twice A C the breadth of the reflector. This circle is divided into six angular spaces, two of which are the first reflections, and other two the second reflections of the inclined glasses. The other two consist of the actual space included between the glasses, and a similar space opposite to it which receives at once the third reflection of both glasses.

Since looking-glasses never reflect *all* the light incident upon them, these reflections will not be as vivid as the direct view of the space B C; nor will they, compared one with another, be equally vivid. The reflections B C′ and C′ C″ will be less vivid than the object B C, but more so than the second reflections C′ C‴ and C″ C⁗. The third reflection C‴ C⁗ would be less vivid than the second C′ C‴ and C″ C⁗, if it proceeded only from one glass as do the latter. But it must be remembered that being the combined reflection of both glasses, the loss of brightness by the multiplied reflections of each glass is to some extent compensated.

4. We have here supposed that the glasses are inclined at 60°, but they may be inclined at any angle which is an aliquot part of 360°. Thus if they are inclined at 90°, the circular space or field of view round A will be divided into four angular parts, and the same observations are applicable. If the glasses are inclined at an angle of 45°, the field of view will be divided into eight equal angular spaces, seven of which will be filled by the reflections.

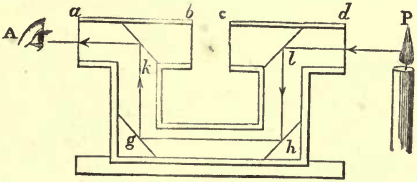
From what has been here explained, the unequal brightness of the angular spaces seen in the kaleidoscope will be understood. If, as is most common, the angle of the glasses be 60°, this is perceptible, but if it be 45°, the repeated reflections so reduce the brightness as to impair the beauty of the effect.

5. The effects of the kaleidoscope are very striking, in consequence of the endless variety of which they are susceptible, even with a single cell at the object end of the instrument; but it may be so arranged that several cells, including different collections of coloured objects, may be provided, and may be changed one for another, fitting on the end of the tube like the cover of the object glass of a telescope.

The effects of this pretty little optical contrivance have been occasionally rendered useful in the industrial arts, in suggesting patterns for carpets and other products of the loom.

6. An amusing optical toy is represented in fig. 3, by means of

Fig. 3.



which objects may be seen, notwithstanding the interposition of any opaque screen between them and the eye. The rays proceeding from the object P entering the tube *d* strike on the mirror *l* placed at an angle of 45°, and are reflected downwards vertically to the mirror *h*, also placed at 45°, from which they are reflected horizontally to the mirror *g* placed at 45°, from which they are again reflected vertically to the mirror *k* placed at 45°, from which they are reflected horizontally to the eye at A. The eye thus sees the object after four reflections, the rays which render it visible having travelled round the rectangular tube *l h g k*.

London, *February*, 1855.

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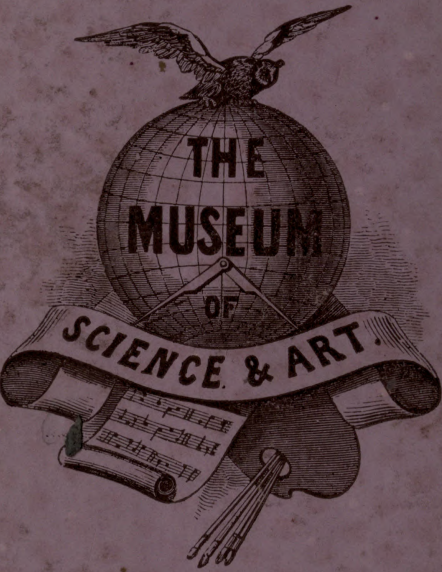
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